ON-FARM ASSESSMENT
OF MAIZE-*MUCUNA* SYSTEMS IN THE
LOS TUXTLAS REGION OF SOUTHEASTERN VERACRUZ, MEXICO

By

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by

Marjatta Eilittä

This work is dedicated to my mother, Aino Eilittä, and to the memory of my father, Eero Eilittä, both of whom taught me the love of the land and its people, and to the memory of Álvaro Velásquez Guzman, who stands as an example for us all in his dedication to improving the lives of others.

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ON-FARM ASSESSMENT OF MAIZE-*MUCUNA* SYSTEMS IN THE LOS TUXTLAS REGION OF SOUTHEASTERN VERACRUZ, MEXICO

By

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Chairman: Lynn E. Sollenberger
Major Department: Agronomy

In recent years, smallholder farmers in the Los Tuxtlas region of southeastern Veracruz, Mexico, have relay-intercropped *Mucuna* in August in June-planted summer maize (*Zea mays* L.). *Mucuna* is slashed in November prior to winter maize planting ("System A"), or senesces without winter maize cultivation ("System B"). The productivity and the factors impacting productivity of these systems were quantified utilizing observational (agronomic monitoring) and experimental methods (on-farm trials). On-farm trials quantified biomass production of the farmer-utilized *Mucuna* varieties, and assessed systems A, B and two alternative systems: "System C" included winter maize cultivation after sole-cropped summer *Mucuna*, while "System D" resembled "A" but with a second *Mucuna* intercrop in winter maize.

Agronomic monitoring revealed relatively low but highly variable *Mucuna* biomass production (leaf+stem, 1.2 t ha^{-1}; SD 0.8 t ha^{-1}). Factors impacting biomass positively were System B utilization, early planting, high planting density, and higher proportion of self-reseeding. Farmers' summer maize yields were generally low but highly variable (averaging 1.1 t ha^{-1}, SD 0.6 t ha^{-1}). Lower yields were generally associated with low maize planting density and higher weediness. It was concluded that *Mucuna*'s average impact on summer maize yield was small or nil due to recency of *Mucuna* use, residue burning, low nutrient content of *Mucuna*, and nutrient losses in System B, among other factors.

On-farm experiments also found no impact of *Mucuna* on summer maize; however, in comparison to the double-cropped no-*Mucuna* control, the summer *Mucuna* intercrop in System A increased winter maize yield by an average of 50%. The winter *Mucuna* intercrop in System D did not decrease maize yield, but overwintered poorly. Sole-cropped summer *Mucuna* in System C increased winter maize yield 50 to 120%. *Mucuna* biomass contained about 50, 100, and 150 kg ha^{-1} of N in systems A, B, and C, respectively. All three *Mucuna* varieties utilized by farmers produced high biomass (4.9 to 7.9 t ha^{-1} including mulch) in System C conditions.

This study showed that combining observational and experimental methodologies, including on-farm trials that mimic farmer conditions, allowed more effective assessment of such heterogeneous farmer-managed systems in diverse environments than did observational methods alone.

CHAPTER 1
INTRODUCTION

The rural Los Tuxtlas region of southeastern Veracruz state, Mexico, exemplifies the links between a deteriorating environment, decreasing farm productivity, and rural poverty in developing countries. Increased in-migration and cattle ranching, together with local population growth, have greatly increased pressure on land, resulting in shorter fallows, impaired soil fertility, and decreased yields, further exacerbating rural poverty (Paré et al., 1994; Paré and Velázquez, 1997; Chavelier and Buckles, 1995; Buckles and Erenstein, 1996).

The marginalized maize farmers of these regions, who never participated in the post-war "Mexican miracle," but have suffered from the budget cuts and economic crises of the 1990s, are today working increasingly degraded soils. The achievement of stable, increased maize yield is imperative for the well-being of the region's families and indeed of the region itself. Only stable and increased agricultural production can ensure food security for the region's poor and offer such gainful employment that out migration from the region is prevented. Central to stable and increased agricultural production is the maintenance or improvement of soil quality.

In recent decades, a great deal of effort on the part of both researchers and extension-oriented organizations has focused on green manure/cover crops (GMCC). The GMCCs have been promoted and researched throughout the tropics, in Mesoamerica (e.g., Wade and Sanchez, 1983; Buckles et al., 1998; Arteaga et al., 1997; Triomphe, 1996), in Africa (Vissoh et al., 1998; Tian et al., 1998; Carsky et al., 1998), and in Asia (Hairiah et al., 1992). The GMCCs are fast-growing, typically leguminous plants with high above-ground biomass production. At least a part of their biomass is left on the soil surface as mulch which can provide multiple soil-related benefits: nutrients, weed suppression, soil structure improvement, moisture conservation, and erosion control (Wade and Sanchez, 1983; Lathwell, 1990; Lobo Burle, 1992). Other uses for GMCCs include fodder and food. The GMCCs can be simultaneously intercropped with the main crop; they can be planted as a relay crop; or the two crops can be planted sequentially at various intensities (Buckles and Barreto, 1996). The main crop in the tropical GMCC systems has either been a staple food crop or a plantation crop. Of the staples, maize has been the most commonly associated with GMCCs.

Among the dozens of well-known GMCCs, the velvetbean (*Mucuna spp.*, hereafter referred to as *Mucuna*) has received the most attention among farmers, extensionists, and researchers, due to its proven potential for rapid growth and abundant biomass production in diverse environments, which often result in high main crop yield increases (Lathwell, 1990; Lobo Burle et al., 1992; Carsky et al., 1998). *Mucuna* has been the focus of both extension efforts and spontaneous farmer adoption, particularly in Mexico and Central America, but also in tropical Asia and sub-Saharan Africa, including the Republic of Benin (Buckles, 1995; Buckles et al., 1998; Triomphe, 1996; Vissoh et al., 1998). Though no systematic quantification of the extent of *Mucuna* utilization exists, Buckles (1995) has estimated that approximately 30 000 farmers in Mesoamerica are utilizing *Mucuna* as a result of spontaneous adoption, while the Sasakawa-Global

2000 project's plans were to reach 100 000 farmers with *Mucuna* technology in the Republic of Benin in 1995 (Vissoh et al., 1998).

Despite the numerous efforts in *Mucuna* research and extension in the past decade, little *ex post* evaluation of GMCC systems, including those with *Mucuna*, has taken place (Carsky et al., 1998). For that reason, little is known about the GMCC systems' variability and range of performance in on-farm conditions. Equally little is known of factors affecting such performance in farmer-managed systems. On-farm assessment of GMCCs and systems is hindered by the great variability encountered in farmer-managed systems. Additionally, research methods for studying such systems are relatively undeveloped.

In the Los Tuxtlas region of southeastern Veracruz, *Mucuna* has been spontaneously adopted by farmers since at least the 1950s, but such traditional use has remained limited (Buckles and Perales, 1995). Since 1991, however, *Mucuna* has become the object of research and extension efforts in the region. A Mexican NGO, the Proyecto Sierra de Santa Marta (Sierra Santa Marta Project), has headed these efforts, while scientists at CIMMYT (the International Maize and Wheat Improvement Center), headquartered in Mexico City, have collaborated with the organization in *Mucuna* research and extension. The focus of the extension efforts and subsequent *Mucuna* utilization have been maize-*Mucuna* relay systems. In these systems, *Mucuna* is intercropped in summer maize, and then either slashed to plant winter maize, or allowed to senesce in the field with no winter maize cultivation.

Although by 1995 the maize-*Mucuna* systems in the Los Tuxtlas region had been reported to enhance the production of maize, little on-farm agronomic work had taken place on these systems after the initial on-farm trials in the area (Buckles and Perales, 1995). Little was therefore understood of the ways in which the farmers had adopted *Mucuna* in their cropping system, of their management of the maize-*Mucuna* intercrop, and of the influence of biophysical factors on the growth of maize and *Mucuna* in this system. Finally, little was known of the impact of *Mucuna* on maize yield in farmer conditions. As indicated earlier, understanding of GMCC systems' on-farm performance is generally lacking, while methods for such assessment are undeveloped.

To address these deficits, this study pursued the following research objectives:

- Characterize quantitatively the field conditions (both management and environmental) in which the adoption of the maize-*Mucuna* systems had taken place;
- Quantify the productivity of maize (grain kg ha^{-1}) and *Mucuna* (biomass kg ha^{-1}) in the farmer-managed *Mucuna* systems;
- Quantify the impact of key management and environmental factors affecting the productivity of maize and *Mucuna* in the farmer-managed systems;
- Quantify the impact of *Mucuna* on productivity of maize in the farmer-managed systems; and
- Evaluate and develop the methodology of agronomic monitoring.

This agronomic assessment of maize-*Mucuna* systems in the Los Tuxtlas started in 1995, 3 years after the initiation of extension efforts. It evaluated two systems practiced by farmers, as well as two alternative maize-*Mucuna* systems. The study utilized both observational and experimental tools. The observational method, agronomic monitoring, focused on summer maize production with and without *Mucuna* intercrop in

1995 and 1996. Concretely, the monitoring consisted of multiple visits to observational plots on farmers' fields throughout the summer season to gather data on maize and *Mucuna* growth, as well as on factors affecting such growth. The methodology and results of the agronomic monitoring are presented in Chapters 4 and 5. The experimental component, consisting of on-farm experiments, included both summer (1996 and 1997) and winter (1995-96 and 1996-97) seasons. The main focus of the trials was a continued assessment of the farmer-practiced maize-*Mucuna* systems in comparison to the no-*Mucuna* and two alternative maize-*Mucuna* systems. An additional trial explored the biomass production potential of the farmer-utilized *Mucuna* types. These experiments, which are presented in Chapters 6 and 7, were designed to replicate farmer conditions in that the management of maize and *Mucuna* in the trials approximated farmer management. Finally, additional experiments were designed to evaluate the impact of N and P on summer maize production; such experiments are described in Appendix A.

CHAPTER 2
MUCUNA PERFORMANCE AND ITS ASSESSMENT UNDER ON-FARM CONDITIONS

Introduction

In recent decades, *Mucuna* has become the object of attention of extentionists and researchers working on improved livelihoods for tropical smallholders. *Mucuna* has been described as "without doubt one of the most popular green manure crops currently grown for the tropics, and a featured example of green manures' contribution to sustainable agricultural systems" (Buckles, 1995, p. 14). A growing body of experimental evidence has documented *Mucuna*'s ability to rapidly establish ground cover, produce a large above-ground biomass, and accumulate nutrients, particularly nitrogen, in various environments. Typically, in trials covering a large number of green manure/cover crop species (GMCC), *Mucuna* has been one of the leading species in terms of biomass production and nutrient content; similarly, *Mucuna*'s beneficial impact on main crop yield has been documented in a number of studies (Lathwell, 1990; Lobo Burle et al., 1992; Carsky et al., 1998). In the overwhelming majority of *Mucuna* studies and cases of farmer utilization, the main crop has been maize.

Key gaps in understanding of *Mucuna* performance persist. Recently, Carsky et al. (1998) reviewed information available on *Mucuna* and suggested a number of research issues, including *ex poste* studies on the biophysical and socioeconomic conditions under which *Mucuna* systems have been adopted. It is clear that information is lacking on *Mucuna*'s growth and impact on main crop yield in environmental and management conditions of tropical smallholders. Though some research data are available on *Mucuna*'s performance in poor fertility soils and in intercropped systems, the amount of such data is limited. Moreover, the impact of management factors on the growth of *Mucuna* has been studied very little. Finally, very few studies to date have focused on assessing the performance of farmer-managed *Mucuna* systems under farmer conditions. While methods for assessing farmer-managed GMCC systems are relatively underdeveloped, the challenges to such assessment are particularly great, especially in circumstances with high environmental and management variability.

This chapter will first briefly introduce *Mucuna* taxonomy and adaptation, after which *Mucuna*'s history as a utilized plant will briefly be reviewed. It will then focus on available research results on *Mucuna* biomass and *Mucuna*'s impact on main crop yield in favorable environmental and management conditions, as well as under conditions that are more typical to those of tropical smallholders. The chapter will conclude by reviewing a relatively little-known method, agronomic monitoring, to conduct on-farm assessment of systems involving GMCC crops. This review focuses on literature available on the genus *Mucuna*.

Introduction to *Mucuna* spp.

Taxonomy and Adaptation

The *Mucuna* genus includes a large number of annual and perennial legumes in the family Fabaceae which originated in China, Malaysia, or India. The cultivated *Mucuna* is a vigorously-growing, twining annual legume that has a multitude of common names (e.g., velvetbean, *pica-pica*, bengal bean, *nescafé*, *ojo de venado*, *pois mascate*, *olhos de burro*; Weber et al., 1997). Following Kay (1979, cited in Carsky et al., 1998) and Wilmot-Dear (1984), for cultivated *Mucuna*, the species name *Mucuna pruriens* (L.) is most commonly utilized today. A number of utilized types that were formerly considered separate species are now considered merely varieties of *M. pruriens: aterrima*, *cochinchinensis*, *hassjoo*, *nivea*, and *utilis* (Kay, 1979; Wilmot-Dear, 1984; Carsky et al., 1998). Such varieties can be distinguished by flower color (white or purple), seed color (black, white, mottled, beige, brown, or gray), pubescence on pod (erect, stinging or adpressed), and leaf size and phenology (Monegat, 1991; Carsky et al., 1998). The early 20th century researchers in Florida differentiated annual *Mucuna* species into genus *Stizolobium* (Bort, 1909); references to *Stizolobium* can still be seen in agronomic literature. In the literature, *Mucuna* accessions are often referred to by seed color. Taxonomic characterization of these varieties is under way at the International Institute of Tropical Agriculture (IITA) in Nigeria, where results of a single-season trial indicate considerable variation among the varieties. For example, seed weight varied between 0.38 and 0.84 g while time to flowering was from 92 to 195 days (Carsky et al., 1998).

Though *Mucuna* is subtropical or tropical, short-season varieties have been grown in temperate conditions as far north as Virginia, USA (Duke, 1981). *Mucuna* is a short-day annual (Duke, 1981), flowering in October-November in the northern hemisphere (Carsky et al., 1998). According to the Legume Expert System (LEXSYS; Weber et al., 1997), *Mucuna* is adapted to a broad range of precipitation (650 to 3000 mm), is moderately drought-tolerant, but grows best under humid conditions (optimum 1000 to 2500 mm yr^{-1}). It is a warm-climate plant growing in 15 to 35°C while its optimum is 19 to 27°C. *Mucuna* is sensitive to frost, tolerating temperatures below 5°C only for short periods (Duke, 1981). It is well adapted to elevation up to 1600 m asl; cultivation to 2100 m has been reported (Weber et al., 1997). *Mucuna* grows in a wide variety of soils, has a wide pH tolerance (from 4.5 to 7.7; optimum 5.0 to 7.0), but does not tolerate waterlogging well.

Mucuna typically nodulates well, but does respond to rhizobia inoculation (Duke, 1981; Sanginga et al., 1996c). Throughout its range, it is relatively free of disease and pests, a characteristic that has been attributed to its L-dopa content (Lorenzetti et al., 1998). However, Monegat (1991) and Legume Expert System (Weber et al., 1997) name a number of pathogens afflicting *Mucuna*, and caution has been urged against the reliance on one species or few cultivars (Carsky et al., 1998). At IITA in Nigeria, an incidence of *Macrophomina phaseolina* has been reported after many years of *Mucuna* rotation (Berner et al., 1992), while in Florida, where extensive cultivation dates to the early 20th century, it is still susceptible to velvetbean caterpillar (*Anticarsia gemmitalis*). Allelopathic properties have been reported in velvetbean (Gliessman, 1983; Hepperly et al., 1992).

Mucuna's Attributes as a Green Manure/Cover Crop

Although the characteristics of an idiotype of a GMCC species are, of course, partly location specific, in general the following characteristics could be named: rapid establishment of ground cover; generation of large amounts of biomass without competitive effects on the main crop, good mulch quality, and photoperiod and thermal responses that allow the crop to fit within a cropping system. Finally, the GMCC would ideally also provide other, more immediate benefits and products, such as weed suppression, food, or fodder.

In many ways *Mucuna* posesses these ideal characteristics. *Mucuna* is known for its ability to quickly establish ground cover, and typically in agronomic studies has been one of the fastest-growing legumes, with relatively strong beneficial impacts on the main crop yield (Yost et al., 1985; Lathwell, 1990; Lobo Burle et al., 1992; Carsky et al., 1998; Monegat, 1991). It produces good quality mulch. For example, Tian et al. (1995) reported that *Mucuna* leaf mulch quality is high, with rapid decomposition and nutrient release. Consequently, it has the potential to increase main crop yield through nutritional effects, as opposed to mulching effects. Moreover, the nematode-suppressing ability of *Mucuna* is well known, though *Mucuna* also supports some nematodes (Carsky et al., 1998; Thurston, 1997; Reddy et al., 1986).

Mucuna's weed-suppressing abilities are well known. Such effects have been attributed both to physical suppression, due to rapid establishment and biomass production, and to allelopathic effects (Carsky et al., 1998). Successful *Mucuna* adoption in Benin has been linked to its ability to suppress *Imperata cylindrica* (Manyong et al., 1996; Versteeg and Koudokpan, 1993), while *Mucuna* intercropped with rice reduced weed populations in Cote d'Ivoire (Becker et al., 1998). Anecdotal reports exist on *Mucuna*'s ability to suppress the parasitic weed *Striga hermonthica* (Carsky et al., 1998).

Differing quantities of seed production have been reported in the literature (Carsky et al., 1998), but it is clear that *Mucuna* is capable of relatively good seed production if the rainy season is long enough to permit growth to maturity. Seed production is increased if *Mucuna* can climb above ground level, e.g. over trees or maize stems.

Mucuna has its drawbacks as a GMCC. Due to its aggressive growth, competitive effects on the main crop have been reported in early intercropping situations (Lopez et al., 1993; Zea et al., 1991; Quiroga, 1994). *Mucuna*'s photoperiod response (short-day plant) may pose a problem for certain systems; its flowering has also been reported to be advanced by cool nights (Keatinge et al., 1996).

Unfortunately, *Mucuna* seeds contain a toxic substance L-dopa, a compound used to treat Parkinson's disease, which is known to cause gastrointestinal disturbances and psychotic reactions, including aggression and hallucinations (Reynolds, 1989, cited by Lorenzetti et al., 1998). Lengthy preparation is required for safe human consumption. Nevertheless, *Mucuna* seeds are utilized as a minor food crop in certain locales, including areas of Ghana (Osei-Bonsu et al., 1995). A recent study (Lorenzetti et al., 1998) determined that L-dopa concentration varied between 2.18% (in Georgia velvetbean from the United States) and 6.17% (in *M. deeringiana*, seed obtained from Brazil). L-dopa concentration varied by seed color (lowest in stippled) and by growing location (highest near the equator); the latter explained 78.2% of the variability in the L-dopa concentration.

There are conflicting accounts of *Mucuna*'s palatability as green fodder or hay (Carsky et al., 1998). It has been widely used as hay (Webster and Wilson, 1980) e.g., in Southern Rhodesia in the 1950s (FAO, 1959). Mucuna is also known to contain antinutritional fractions, such as phenols and tannins (Lorenzetti et al., 1998).

History of *Mucuna* Utilization

During its history as a cultivated crop, the main centers of use and interest in *Mucuna* have shifted back and forth between tropical and the temperate regions. Recently, Buckles (1995) reviewed *Mucuna*'s fascinating history.

Prior to the late 19th century, farmers throughout the tropics made use of *Mucuna* for soil improvement and as a fodder and minor food crop. The earliest reported utilization of *Mucuna* as a green manure is from 17th-century Java, Sumatra, and Bali. Utilized in the 18th and 19th centuries as a green vegetable in Mauritius, *Mucuna* also has had a long history as a minor food crop in India (Buckles, 1995).

From the late 19th century until the 1940s, *Mucuna* was widely utilized and studied in the southeastern United States. It apparently came to Florida in the 1870s from the Caribbean where it had been introduced by Indian workers in the 19th century (Buckles, 1995). In Florida, *Mucuna* was first utilized for two decades only as an ornamental (Clute, 1896). Once its soil-improving qualities and fodder potential were discovered around 1895, rapid adoption (typically as a maize intercrop) followed. By 1902, *Mucuna* was being marketed as a cattle feed (Miller, 1902). Short-season varieties, the products of breeding efforts and spontanous arisal, soon were cultivated throughout the Southeast (Scott, 1919); *Mucuna* became a permanent feature of Southern agriculture until the Second World War. At that time, agricultural experiment stations and universities in the southern states conducted research on *Mucuna* as a fodder crop and soil improver, while *Mucuna* breeding programs were active from 1908 until 1940s (Scott, 1946; G. Prine, personal communication). Annual extension reports in Florida attest to the importance which *Mucuna* and other leguminous plants were given during the early 20th century.

Work in the southeastern USA appears to have stimulated early 20th century experimentation with and utilization of *Mucuna* in the tropics. Researchers in Nigeria (Vine 1953, cited in Carsky et al., 1998) and Rhodesia (FAO, 1959) conducted work on *Mucuna*, while in Guatemala during the 1920s, the lowland Ketchi farmers adopted *Mucuna* in their maize systems from its cultivation as a fodder crop in United Fruit's 1920s banana plantations (Buckles, 1995). *Mucuna* then spread among Mesoamerica's smallholders (Buckles, 1995). In Mexico since the 1940s, smallholder farmers in several states, including Chiapas, Tabasco, Oaxaca, and Veracruz, have cultivated *Mucuna* in their maize fields (Guerrero, 1995; Narvaez and Paredes, 1994; Garcías et al., 1994). Buckles (1995) estimates that currently *Mucuna* has been spontaneously adopted by approximately 30 000 smallholder farmers in Mesoamerica. Meanwhile, traditional use as a minor food crop continues in Ghana, Nigeria, Mozambique, and India.

There was a resurgence of interest in *Mucuna* among researchers in the 1980s. Especially influential projects were those carried out at IITA (1993) and at the TROPSOILS program site in Central Brazil (Lathwell, 1990; Lobo Burle et al., 1992), while in Southern Brazil *Mucuna*-related research and extension activities developed in relative isolation (Calegari et al., 1997; Monegat, 1991). IITA's work largely focused on *Mucuna*'s potential to suppress weeds and improve soil quality, generating baseline data and playing an instrumental role in the stimulation of farmer interest and large-scale promotion efforts in the Republic of Benin (IITA, 1993; Versteeg and Koudokpon, 1993; Versteeg et al., 1998). The TROPSOILS program's evaluation of a great number of green manure species in Brazil in the 1980s (Lathwell, 1990; Lobo Burle et al., 1992) provided data on *Mucuna* growth and its impact on main crop yield. Increasingly in the 1990s, a wide variety of organizations have started to incorporate *Mucuna* into their research and extension programs in Mesoamerica, Africa, and Asia. For example, in 1995 the Sasakawa-Global 2000 project targeted 100 000 farmers with *Mucuna* extension in the Republic of Benin (Versteeg et al., 1998). By the mid-1990s, Buckles (1995) estimated that 50 organizations were actively promoting *Mucuna* in Central America and Mexico alone.

Systems of *Mucuna* Use

Considerations of system niches for *Mucuna* is particularly important. At the moment, *Mucuna* is promoted mostly in associations with a main crop that provides the direct benefits as food or marketable products for the farmer.

Recently, Buckles and Barreto (1996) conceptualized the process of temporal and spatial intensification which occurs in tropical agriculture as fallowing is succeeded by the utilization of cover crops. Such a conceptual framework is very relevant for *Mucuna*, as it helps to set in context the various types of systems in which *Mucuna* has been utilized.

The authors characterize three strategies for intensification. The least intensive of such strategies is the *rotational system*, where the cover crop is grown immediately prior to the main crop as a sole crop, typically occupying the growing season with higher rains. In the *relay system*, the cover crop is planted relatively late in the main crop's season, which is typically cultivated in the main, rainy season. Finally, in the *intercropping system*, the cover crop is planted during the first days of the main crop. The authors surmise that the humid zone provides suitable conditions for any of the intensification strategies, while the relay systems and early intercropping are most promising in zones with a significant dry season and shorter growing period (180 to 270 d). Arid zones, with growing periods of less than 180 d, are the most challenging environments for agricultural intensification through the utilization of cover crops.

It can be generalized that much of the past spontaneous *Mucuna* adoption (resulting in "traditional systems") in Central America and Mexico has been in the form of a rotational system. In such systems, *Mucuna* has been intercropped in winter (second-season) maize, but cultivated during the rainy season as a sole crop, and slashed immediately prior to winter maize cultivation. Such systems are quite widespread throughout Mesoamerica (Figure 2-1). Much of the more recent promotion of *Mucuna* has, however, focused on the temporally and spatially more intensified systems, namely relay intercropping and early or simultaneous intercropping.

The authors argue that the three intensification strategies differ in several important agronomic aspects. In the rotational system, potential for competition with the main crop is nil (due to the different growing periods), while variability in biomass production is low (due to absence of competitive effects by the main crop, as well as the long growing period and sufficient rainfall of the humid zone). In contrast, in the intercropped systems there is high potential for competition, and high biomass variability, while the relay systems are intermediate in these respects.

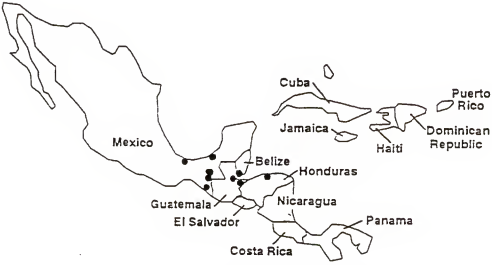

Figure 2-1. Locations in Mesoamerica where *Mucuna* has been spontaneously adopted. Source: Buckles et al., 1998.

These systems differ in socioeconomic aspects as well. Labor requirements and learning costs are lowest in the rotational system. However, the opportunity costs of the rotational system are high, due to cover crop's occupation of a full growing season.

Despite the recent interest in *Mucuna* research in the past two decades, it is clear that our knowledge base is still relatively shallow. The following review mainly focuses on published research results on *Mucuna* biomass production and impact on main crop yield.

Mucuna's Biomass Production

Mucuna's biomass production has been the focus of many investigations, including this study. High biomass production is associated with many of the benefits that are expected from a GMCC species. However, simplistic comparisons of biomass production without regard to impacts on the main crop, or among different *Mucuna* systems, have only limited value.

Research Focus on GMCC Biomass Production: Benefits and Limitations

Tian and Kang (1998) state that the contribution of a legume to soil improvement and crop production depends primarily on biomass production and the chemical composition of such biomass. It is not surprising that the biomass achieved by GMCC is, for several reasons, of utmost importance to its eventual contribution in a cropping system. First, it is evident that the biomass of a GMCC is directly related to its N content. Due to N losses that occur, especially in systems where the green manure is left as a cover (Costa et al., 1990; Hargrove, 1988; Janzen and McGinn, 1991; Glasener and Palm, 1995; Larsson et al., 1998), the biomass production of the GMCC must reach a critical limit to make any N contribution to the main crop. This limit has been estimated at 2 t ha^{-1} of dry matter (Lobo Burle et al., 1992). Second, many of the mulch-related benefits naturally depend on biomass production that is adequate to form a substantial mulch layer (Lal, 1975). Given that Carsky et al. (1998) estimate that approximately 1 t ha^{-1} of mulch is lost per month of dry season, more than 2 t ha^{-1} is needed to maintain continued mulch in areas with pronounced dry season lasting several months. Third, research results indicate that in *Mucuna*, the amount of biological N_2 fixation is associated with the amount of biomass produced. Sanginga et al. (1996c), working with moist savanna cropping systems, found that increased *Mucuna* growth was associated with increased N_2 fixation, and concluded that "biomass production should be the first criterion for maximizing N_2 fixation" (p. 447) in these cropping systems.

However, it should be emphasized that research focused narrowly on biomass accumulation alone can have limited value, even in purely agronomic studies since high GMCC biomass does not necessarily translate into improved system performance. Firstly, the biomass accumulation should of course not take place at the expense of the main crop. For example, in the case of relay intercropping *Mucuna* in maize, planting *Mucuna* prior to 35 to 40 days after planting (DAP) maize may maximize *Mucuna* biomass, but will result in competition with maize (Quiroga, 1994; Vissoh et al., 1998). The "fate" of GMCC biomass, i.e., its loss, utilization, or mineralization, and the availability of mineralized nutrient to the main crop, may greatly vary by system due to the environmental and management conditions to which such biomass is exposed. Thus the benefits of increased biomass may be system specific, rendering comparison of biomass amounts across systems of limited value.

If such limitations are kept in mind, focus on biomass production does give a measuring stick of a sort for an assessment of the productivity of a GMCC species. In the following, available experimental data on *Mucuna* biomass production in high production environments is described first, after which attention turns to various potential limitations to *Mucuna* biomass production under circumstances which are typical of tropical smallholder conditions. Caution should be used when comparing biomass production across studies, as biomass measurements are often inadequately described, and it is not always clear which biomass fractions are included in the data presented.

Production in Favorable Conditions

Various studies have confirmed high biomass production of sole-cropped *Mucuna* in favorable soil and climatic conditions. In the TROPSOILS program trials in Brazil, *Mucuna* grown during the rainy season produced up to 8.5 t ha^{-1} of above-ground dry matter, containing 252 kg of N (Lathwell, 1990). That such biomass was obtained in a high production environment is confirmed by the high maize yields (4900 kg ha^{-1}) in the control plots receiving no fertilization. Ravindran (1988), researching *Mucuna*'s potential as a fodder crop in Central Sri Lanka, cultivated *Mucuna* at a relatively high density (60 cm by 60 cm, 2 per hill) and with organic fertilizer (equivalent to 52, 36, and 35 kg ha^{-1} of N, P_20_5, and K_20, respectively). *Mucuna* dry matter yields at 60, 90, 120, and 150 DAP were 1.7, 3.1, 4.4, and 5.3 t ha^{-1}, respectively.

Gordón et al. (1993) found in Panama that May-planted *Mucuna* produced 6.1 and 5.9 t ha^{-1} of biomass by September containing 211 and 202 kg N ha^{-1}. Cahn et al. (1993) found that *Mucuna* planted at 80 DAP maize at a high density (15 cm between hills, 50 cm between rows) produced biomass up to to 6.8 t without liming, and 7.7 t with liming.

High biomass production has also been measured in favorable on-farm conditions. Triomphe (1996; Buckles et al., 1998) found an average dry matter biomass production of 11.7 t ha^{-1} (SD 2.5) across study years; average minimum biomass across years was 6.1 t ha^{-1}, while average maximum biomass was 17 t ha^{-1}. Similarly, Sanginga et al. (1996a) measured high biomass in farmer conditions in Southern Benin. Research results indicate that such high biomass production is linked to the benefits obtained from *Mucuna*'s seeds, which are large and high in nutrient content (Adewole and Kang, 1997).

Potential Limitations to Biomass Production Under Farmer Conditions

Demonstrating high potential biomass production for sole-cropped *Mucuna* in high-production environments tells little of *Mucuna*'s growth potential in the typical conditions of tropical smallholder systems where it is needed most. In such systems, *Mucuna*'s growth may be affected by a number of factors, several of which may be related to the placement of *Mucuna* in the cropping cycle. For example, due to land pressure, *Mucuna* may need to be cultivated during the dry season or it can only be intercropped. Many biophysical factors may also affect *Mucuna*'s growth potential, such as poor fertility and acid soils. Finally, *Mucuna* management in such conditions may be variable, and often suboptimal. In the following, available research findings on the impact of such factors on *Mucuna* growth are presented.

Production in dry season conditions

Mucuna is relatively sensitive to long dry periods; senescence in the beginning of the dry season has been reported, e.g., from semi-arid Cameroon (Carsky and Ndikawa, 1998). Some interesting research results are available on attempts to utilize the dry season for *Mucuna* production. Lobo Burle et al. (1992) evaluated *Mucuna* growth during the dry season in subhumid conditions in Brazil. *Mucuna* was planted at the end of the rainy season and established during the dry season. *Mucuna* underwent a period of rapid biomass accumulation in the beginning of the rainy season, after which it was slashed and the main crop planted. In the dry season, *Mucuna* spp. produced from 2.2 to 4.7 t ha^{-1} in a dark red latosol, while in a red yellow latosol such production was only 0.8 to 2.9 t ha^{-1}; *Mucuna* management, however differed between the two soils (Lobo Burle et al., 1992). In another trial, with liming and P plus K fertilizer, *Mucuna* dry-season biomass production during three consecutive years was 3.4, 2.2, and 5.7 t ha^{-1}. (The lowest production occurred in a year with no rainfall in the dry season subsequent to *Mucuna* planting). In this trial maize yields after a no-*Mucuna* fallow were 4160, 1325, and 3380 kg ha^{-1} (Lobo Burle et al., 1992).

Impact of fertility on *Mucuna* production

Views differ on *Mucuna*'s potential in low-fertility soils. Certain reports indicate that *Mucuna* has good potential even in exhausted soils under favorable rainfall (Soil Fertility Network, n.d.), while others (Dreschsel et al., 1996), basing their review on green manure experience in Rwanda, conclude that *Mucuna* is less adapted to marginal soils with low fertility. In Brazil, Calegari et al. (1997) report that *Mucuna* is reserved for more degraded soils, where it may typically be grown for two consecutive years, while in Nigeria, Wilson and Akapa (1982) found that *Mucuna* had the fastest growth when grown 2 yr as a soil restorer on an eroded Alfisol.

The impact of low soil fertility on *Mucuna* growth as well as its response to fertilizer have increasingly become a focus of research efforts. These researchers have particularly focused on *Mucuna* growth under low P conditions, and its response to P due to the importance of P in N_2 fixation. In a pot experiment at IITA, Nigeria, Tian and Kang (1998) compared the growth of 12 legumes in high and low fertility soils, and without and with NPK fertilizer. Of the legumes evaluated after the 18-week growth period, *Mucuna* produced the highest total biomass (combined shoot, root, and nodule) in the high and low fertility soils without fertilizer, and in the high-fertility soil with fertilizer. In the low-fertility soil with fertilizer, *Mucuna*'s biomass production was the third highest of the 12 legumes. In the poor-fertility growing conditions with no fertilizer, *Mucuna* partitioned more dry matter to the roots (41%) than in the other treatments (23-25%). Across species and soils, total dry matter production was 154% higher with fertilizer. The authors, though cautious of extrapolating from pot experiments to field conditions, concluded that for species like *Mucuna* in such low-fertility soils, root decay may be an important avenue for N supply for main crops especially due to high N concentration in the root fraction.

Also at IITA, a second pot and field experiment focused on the impact of soil fertility and P fertilizer on *Mucuna* growth (Tian et al., 1998). The study found differences in *Mucuna*'s response to applied P by soil fertility level and by variety. In the un-manured soil, significant P-response ($p<0.05$) was found only in the shoot production of white-seeded *Mucuna* (increasing from 9.9 to 13.7 g/pot with P) while in the manured soil, P application increased the root (from 6.8 to 10.6 g/pot) and shoot (from 10.7 to 23.7 g/pot) production of the black-seeded variety, and the shoot production (from 17.7 to 29.5 g/pot) of the white-seeded variety. Of the eight legume species evaluated, *Mucuna* varieties showed highest dry matter production of roots in both soil types, and of shoots in un-manured soil. In manured soil, white-seeded *Mucuna* had the highest and black-seeded *Mucuna* the third highest biomass. Phosphorus increased the nodule weight of black-seeded *Mucuna* grown in un-manured soil and white-seeded *Mucuna* grown in manured soil. Response to P was not as pronounced in the field experiments. The authors concluded that P should be applied to those legumes that respond substantially, including the white-seeded *Mucuna*.

Somewhat contradictory results were obtained by Sanginga et al. (1996b) who evaluated eight species during a 14-wk growing period. In a degraded field in the absence of P, black-seeded *Mucuna* had the lowest average shoot dry matter per plant (21 g), while that of white-seeded *Mucuna* was fourth (35 g); the highest biomass was 60 g. However, in the degraded soil the white-seeded *Mucuna* had a very high P response, with a consequent highest biomass (205 g), while the black-seeded *Mucuna* averaged a biomass of 55 g with P (second lowest).

It thus seems clear, that although *Mucuna* growth is impaired by poor fertility, its biomass production is relatively high in poor soils in comparison to other GMCC species. Moreover, variability seems to exist among *Mucuna* varieties in their performance in poor soils. Differential P response has been attributed to varying ability to assimilate P, especially at low levels (Sanginga et al., 1996b). It should be noted that characterization of such variability allows not only the identification of those varieties that respond to P fertilization (Tian et al., 1998), but also those that grow relatively well in nutrient-deficient soils (Sanginga et al., 1996b).

Impact of soil acidity on *Mucuna* production

Acid soils are prevalent in the tropics (Sanchez, 1976). The impact of soil acidity and associated high aluminum levels on the growth of *Mucuna* have been extensively studied by Hairiah (1992; Hairiah et al., 1991; Hairiah et al., 1992, Hairiah et al., 1993a), working both in eastern Nigeria and Indonesia. In a laboratory experiment, she determined that *Mucuna* is relatively tolerant of aluminum toxicity, but typically grows relatively shallow roots in soils with aluminum; consequently it is not particularly drought-tolerant on such soils (Hairiah, 1992). Decreased biomass production was observed when *Mucuna* was planted in a field where the topsoil had been removed to expose the more acidic subsoil. Shoot biomass was more affected than root biomass. Further studies showed that in a heterogeneous medium where a relatively acidic subsoil lays below a less acid topsoil, *Mucuna* may avoid an aluminium-rich subsoil by preferential root growth in the topsoil. Such mechanism was not observed if *Mucuna* received adequate P (Hairiah et al., 1993b).

Yost et al. (1985), in evaluating legumes grown from pH 4.7 to 6.9, found that dry matter production increased with rising pH up to the level of slight acidity (pH 6.0). In comparison to the other legumes evaluated in the study, *Mucuna* was relatively tolerant of low pH. However, its N yield at pH 4.7 was 36% of the maximum, and so limited that its N content was less than that of maize. High biomass production has been obtained on acid soils if liming is employed in a low pH (4.2-4.3) central Amazon Oxisol in a high rainfall zone (2420 mm); Smyth et al. (1991) documented *Mucuna* biomass production of 7.0 to 10.7 t ha^{-1} at flowering after 3 to 3 1/2 mo of growth.

Impact of intercropping on *Mucuna* biomass production

Relatively little quantification of *Mucuna* production has taken place in intercropped systems (Gilbert, n.d.) despite the fact that much of the recent *Mucuna* promotion has been on such intercropped systems. Sanginga et al. (1996a) reported an almost 50% reduction (from 313 to 166 kg ha^{-1}) in the N content of intercropped *Mucuna* in comparison to sole-cropped *Mucuna* at 12 WAP in farmer-cultivated fields in the Republic of Benin.[1] In a bimodal rainfall zone in the derived savanna at IITA, Sanginga et al. (1996a) found that as a sole crop *Mucuna* accumulated 9.2, 7.7, and 8.7 t ha^{-1} for inoculated, uninoculated, and N fertilized treatments, respectively, but that intercropping reduced production by 44, 25, and 56% for the three treatments, respectively. Gilbert (n.d.), reporting from Malawi, found that the *Mucuna* biomass in sole-cropped conditions (6 t ha^{-1}) fell by one half (3 t ha^{-1}) in intercropped conditions, and was only one sixth (1 t ha^{-1}) if *Mucuna* planting was delayed to avoid competitive effects on maize.

In Zimbabwe, Muza (1998) intercropped *Mucuna* with maize in four areas with differing rainfall (1000, 800, 800, and 650 mm yr^{-1}). When intercropped at 4 WAP maize, above-ground biomass of *Mucuna* was relatively high in all but one location: 4470, 10 560, 3150, and 660 kg ha^{-1}, respectively. Later planting dates reduced biomass considerably. When planted at 6 WAP maize, *Mucuna* biomass was only 180, 460, 1790, and 220 kg ha^{-1}; at 8 WAP it was 0, 250, 450, and 50 kg ha^{-1}, respectively. Though the cause of decreased biomass was not discussed, decreasing rainfall would seem to be the probable cause.

Impact of management factors on *Mucuna* production

Little or no data exist on the impact of several important management factors on *Mucuna* biomass production. Among these are planting density and weed management.

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[1] However, authors cited personal communication with an investigator who reported no difference in biomass in intercropped and sole-cropped *Mucuna* at 20 WAP.

Mucuna planting densities under experimental conditions have seemingly varied widely, but no published research results exist on the impact of such planting densities on *Mucuna* biomass production. Indeed, the selected planting density is often not mentioned in research publications, despite the fact that its impact may be quite strong, both on final biomass yield and on the rapidity of establishment of ground cover.

In experimental situations, *Mucuna* has often been sole-cropped at relatively high densities. Becker and Johnson (1998) broadcast *Mucuna* in a standing rice crop (*Oryza sativa* L.) approximately 1 mo before harvest in Cote d'Ivoire at density of 100 000 plants ha^{-1}, while the Soil Fertility Network (n.d.) research in Zimbabwe was conducted with planting density of 148 000 plants ha^{-1}. Hairiah et al. (1991) sole-cropped *Mucuna* at 80 000 plants ha^{-1}, and Yost et al. (1993) sole-cropped at 55 000 plants ha^{-1}. As mentioned earlier, planting densities in intercropped conditions have typically been lower.

Though *Mucuna's* impact on weeds has received a fair amount of research attention, the impact of weediness on *Mucuna*'s biomass production has not explicitly been the object of studies. Carsky et al. (1998) point out that *Mucuna* hardly needs to be weeded if spaced properly and growing normally. However, research and extension reports from early 20th-century Florida indicate that for good *Mucuna* growth, it was considered important to cultivate fields to decrease weed pressure (Scott, 1946). *Mucuna* volunteers can, of course, themselves become weeds of the main crop (Carsky et al., 1998).

Mucuna's Impact on Main Crop Yield

Mucuna's impact on main crop yield has been the focus of a number of studies. Such focus is quite justified, in that positive impacts on main crop yield can greatly stimulate adoption of resource-conserving technologies by smallholder farmers, who by necessity focus on short- to medium-term production effects (Sain and Barreto, 1996; Erenstein, 1997). Moreover, yield gains can more rapidly be detected than changes in soil characteristics (Kang et al., 1997), and can thus act as indicators of anticipated future soil-conservation benefits. Most studies have focused on *Mucuna*'s impact on maize; systems involving other crops and *Mucuna*, such as beans (*Phaseolus vulgaris* L.), chillies (*Capsicum annuum* L.), lemons (*Citrus limon* L.), sorghum (*Sorghum spp.* Moench), and rice (*Oryza sativa* L.), have also been promoted and/or researched (Becker et al., 1995; Becker et al., 1998; Becker and Johnson, 1998; Arteaga et al., 1997; Quiroga, 1994; Quiroga and Bran, 1993).

Impact on Yield in Rotational Systems

A relatively large number of studies focusing on *Mucuna*'s performance in rotational systems have addressed its impact on the main crop, typically documenting clear and positive impacts of *Mucuna* on main crop yields. Work conducted by the TROPSOILS program at the EMBRAPA/CPAC site in Planaltina and Manaus, Brazil (Lobo Burle et al., 1992) focused on maize yield after a dry-season *Mucuna* fallow which was either left as mulch or incorporated. In the first year, maize yield in previously fallowed plots with no added N was 4160 kg ha^{-1}, while yield in plots with previous *Mucuna* was 4995 kg ha^{-1}. There was little difference between *Mucuna* and no-*Mucuna* plots at the 50, 100, or 200 kg ha^{-1} levels of added N. In Year 2 (an unusually rainy early season), when *Mucuna* was left as a surface mulch, yield in the previous *Mucuna* plots exceeded those with previous fallow at all N levels. In the third year, trends were not as clear. *Mucuna*'s fertilizer replacement value was approximately 20 kg N ha^{-1} which was less than in other experiments conducted in the region. In the Manaus experiment, maize yields were lower (at 1 200 kg ha^{-1} without fertilizer) and *Mucuna*'s fertilizer replacement value was 25 to 30 kg N ha^{-1}.

Van Noordwijk et al. (1995), reporting on work done on acid soils (pH 4.5-5.0) in Indonesia, found slight maize yield increases for a crop grown after sole-crop *Mucuna*; urea fertilizer equivalent of *Mucuna* was 57 kg ha^{-1}. Smyth et al. (1991) found that *Mucuna* cut and incorporated at flowering increased maize yields as much as 39, 73, and 109 kg of fertilizer N in the three study years. In the review of *Mucuna* research by Carsky et al. (1998), fertilizer replacement values for incorporated *Mucuna* were between 39 and 150 kg ha^{-1}, while for *Mucuna* left as mulch, they were between 10 and 30 kg ha^{-1}.

Impact on Yield in Intercropping Systems

In intercropped systems, the direction and magnitude of *Mucuna's* impact on the main crop yield is to a great extent determined by the timing of *Mucuna* planting. *Mucuna*'s impact on maize yield was the focus of a research project conducted across Central America at 24 experimental sites with variable production (averaging 1 to 6 t ha^{-1} of maize grain across treatments) (Zea et al., 1991). In 11 sites in 1989, *Mucuna* was intercropped into maize at 0 to 15 DAP maize. In 13 locations in 1990, Mucuna was planted simultaneously with maize but slashed two to three times to avoid competition.

At planting, P (20 and 40 kg ha^{-1}) and S (20 kg ha^{-1}) were applied while 100 kg N was applied in two splits. *Mucuna* was planted at 44 000 plants ha^{-1}. In both years, *Mucuna*'s presence decreased maize yield; such decrease was less than 1 t ha^{-1} at both P levels and both years.

Drechsel et al. (1996), when reviewing green manure experience in Rwanda, reports that effects on the following year's main crop from intercropped green manures are similar to sole-cropped despite their lower planting densities and competition. Carsky et al. (1998), in discussing maize-*Mucuna* relay intercropping points out that "it is debatable whether mucuna intercropping can contribute sufficiently to soil fertility maintenance to be attractive to farmers" (p. 29) due to reduced biomass of *Mucuna* and competitive effects of *Mucuna* in the first season.

Impact of Time Lag Before Next Crop's Planting

Several researchers report a decreased impact on the main crop yield when maize planting does not immediately follow *Mucuna* slashing and/or incorporation. The impact of delayed planting has not been an object of researchers' attention, but has rather happened inadvertently when, for example, rainfall conditions have forced the postponement of the planting. For example, Lobo Burle et al. (1992) report lower than expected recovery of legume N by maize when residue incorporation was delayed by 2 mo.

Though much of the research on *Mucuna* systems has been conducted on rotational systems where main crop planting has immediately followed *Mucuna* slashing, some experimental results are available with considerable lag times between the two. Ile et al. (1996) working in a high rainfall (2400 mm) area with a highly degraded acid Ultisol (pH 4.3) in eastern Nigeria, found that in December 40% of the above-ground vegetation (900 kg ha^{-1}) was of August-planted *Mucuna* origin; 50% of such mulch remained in April at maize planting. Maize yield of *Mucuna* plots averaged 320 kg ha^{-1}, while in the previously fallowed plots it was 182 kg ha^{-1}; yields with urea were highest at 710 kg ha^{-1}. Though the popular *Mucuna* system in the Republic of Benin includes a lag time of several months prior to maize planting, this system has been reported to increase maize yield considerably (IITA, 1993; Vissoh et al., 1998). For example, Versteeg and Koudokpon (1993) report an 80% yield increase in *Mucuna* plots in comparison to plots that were previously cropped with maize.

Impact of Residue Management

Mucuna's impact on main crop yield can, of course, be affected by the management of its residues. Some studies have focused on the impact of incorporation of the residues as compared to leaving them as a mulch. Smyth et al. (1991) compared several *Mucuna* residue management options. Typically, maize yields were lower in *Mucuna* plots where only *Mucuna*'s roots were left, suggesting that most of the N benefitting maize growth came from *Mucuna*'s above-ground biomass. For three study years (1984-86), grain yield in the un-fertilized control was 2.3, 1.1, and 0.4 t ha^{-1}, while in the root-only treatment yield was 1.9, 0.7, and 0.4 t ha^{-1}, and top-only (no roots) treatment yielded 2.8, 1.2, and 1.2 t ha^{-1}, respectively. Grain yield did not differ whether *Mucuna* was fully incorporated or left as surface mulch.

The impact of burning of *Mucuna* crop residues, a practice common among tropical smallholders, has received researcher attention. The contradictory results might be caused by differences in soil fertility and amount of dry matter generated by *Mucuna* across regions. A 17-yr study of *Mucuna*-maize cropping conducted in southwestern Nigeria between 1932 and 1950 detected no difference in the subsequent maize crop yield whether relay-cropped *Mucuna* was incorporated green or as ash (Vine 1953, cited in Carsky et al., 1998; Webster and Wilson, 1980). However, soil nitrate concentration was consistently higher in the no-burn treatment. More recently, Becker et al. (1998) in Cote d'Ivoire evaluated the impact of residue management on subsequent upland rice yield. Rice yield in plots with prior legumes (average yield of legume plots, including one with *Mucuna*) was 0.88, 0.93, 1.05, and 1.15 when legume residues were removed, burnt, mulched, or incorporated ($LSD_{0.05}$=0.23).

One last issue relevant to residue management is the loss of residues during the dry season. In reviewing studies focusing on such losses, Carsky et al. (1998) have estimated that approximately 1 t ha^{-1} of *Mucuna* mulch is lost per month of dry season; maximum biomass during the growing season and length of the dry season therefore determine whether any residues remain to protect the soil at the beginning of the rains.

In the following, discussion will turn to ways of assessing *Mucuna* performance in on-farm conditions.

On-farm Assessment of *Mucuna*'s Performance

Few agronomic studies have been conducted on farmer-practiced *Mucuna* systems. The most detailed of such studies is that of Triomphe (Triomphe, 1996; Buckles et al., 1998), which focuses on nutrient dynamics of the spontaneously adopted rotational maize-*Mucuna* system in Honduras. Triomphe found that in the farmer conditions of the Atlantic Honduras, *Mucuna* was able to generate a large amount of biomass (averaging 11.4 t ha^{-1}, including mulch), that among-field variability in such biomass production was relatively low, and that the system was relatively stable and enabled the production of relatively high-yielding maize. In the system, nutrient release by *Mucuna* seemingly was synchronized with maize nutrient needs.

In an on-farm study evaluating a recently adopted and promoted maize-*Mucuna* system in the Southern Republic of Benin, Sanginga et al. (1996a) measured biomass production and symbiotic N fixation. Utilizing short-term surveys, they studied 34 farmers' fields and found great variability in mycorrhizal infection rate of *Mucuna*, while nodulation was found in 79% of the fields. *Mucuna* biomass at 12 WAP was greatly reduced by intercropping.

The relative paucity of on-farm studies of GMCC systems appears to be a significant shortcoming with potentially serious consequences. Future research efforts will not be targeted correctly if farm-level factors governing GMCC performance are not known. Likewise, if agronomic success is not recognized in the field, successful technologies may be overlooked due to institutional or extension failures. Finally, research and development efforts on the GMCC systems will little profit future work in agricultural development in the absence of an agronomic accounting.

The methodological challenges posed by this task are great. Traditional agronomy's methodological tools are insufficient to assess crop growth and factors affecting it in diverse, farmer-managed fields. Agronomists have customarily relied on controlled conditions at experiment stations to understand, quantify, and improve biological relationships. Especially lacking are agronomic methods for assessing and studying complex systems such as those utilizing GMCCs in on-farm conditions.

The following discussion will address the potential of agronomic monitoring, an observational method of agricultural research. In this study, it was assessed in comparison to more commonly utilized on-farm trials. The potential of agronomic monitoring to study complex systems in diverse environments will receive particular emphasis.

Agronomic Monitoring As a Tool to Study *Mucuna* Systems

The observational method, found commonly in other fields of study, such as medicine, has been little utilized in agronomic research. In general, observational methods approach research questions by essentially creating a hypothetical experimental design. If such hypothetical experimental conditions can be created in an observational study, the experimental methods that the discipline of agronomy has utilized can benefit the design and analysis of such observational studies. The challenges of observational studies in agronomy remain great, however; perhaps the greatest challenge is how to design and analyze data in the face of the variability encountered in farmer conditions.

The importance of close observation of farmer conditions was highlighted by Farming Systems and Cropping Systems Research, which conceptualized the research process as starting from a diagnosis of production problems, proceeding to design of trials assessing improvements, and then moving on to extension. The "diagnosis" stage in this approach could usefully include agronomic assessment at the field level; however, in practice, the diagnostic stage of farming systems research has often emphasized economic issues at the expense of agronomic ones (Byerlee et al., 1991).

Agronomic monitoring of farmers' fields, an observational method of agronomic research, has mainly been developed by French researchers who have worked both in France and in developing countries (Byerlee et al., 1991). Outside of France, investigators at the International Maize and Wheat Improvement Center (CIMMYT) have been prominent users of the methodology. Such agronomic monitoring typically consists of periodic visits to fields to observe and measure crop growth and factors affecting it, combined with farmer interviews to understand the context of the farmer's decision-making (Scopel, n.d.). The greatest challenge in agronomic monitoring is the variability encountered in farmer conditions which makes it difficult to determine factors impacting crop growth. Interestingly, some investigators consider that a great strength of agronomic monitoring is that it forces the researcher to be exposed to farmer conditions, including marked variability (Scopel, n.d.).

Recently, Doré et al. (1997) characterized a two-stage method used in both developing and industrialized countries to diagnose factors impacting regional crop yield variations. The first stage of diagnosis is an analysis of yield formation on farmers' fields. Such analysis is conducted by using pairs of fields which differ in only one environmental or management factor. Essentially controlled conditions are created by an appropriate selection of fields (or plots within a field). Models are then built to understand the process of yield build-up. Finally, this understanding of crop yield build-up in individual fields or settings is compared to that of other fields in the study. The second stage of diagnosis – mainly utilizing general agronomic knowledge - focuses on delineating the management and environmental factors which cause yield differences.

Such a methodology for assessing yield would appear to be ideal. Unfortunately, however, it presupposes certain circumstances that are typically lacking in situations where a resource-conserving technology has recently been introduced. A researcher setting out to assess the agronomic performance and factors impacting such performance on farm often faces a number of burdensome methodological constraints:

- The number of fields in which the study can be conducted may be small due to recent and limited adoption of the technology. Often, in such cases little field selection is possible.
- GMCC and other resource-conserving technologies are typically promoted in marginal environments with extreme variability between and within fields. Thus, it is difficult to utilize pairs of fields where only one management or environmental characteristic differs.
- Due to the recency of adoption, management of new technologies may not be stable, as a great deal of farmer experimentation will be taking place. Extension advice is often constantly evolving as well. Thus, farmer management practices change from year to year, making it difficult at times even to define the system studied, let alone quantify the impact of management on its performance.
- In conditions of recent promotion, the researcher also typically faces a risky research environment. Long-term adoption of the technologies is unsure; as is the continuation of farmer use throughout the period of study. Consequently, to ensure continuity in a sufficient number of fields, the researcher has to

begin by monitoring an overly large number of fields; this hinders in-depth analyses. Moreover, complex designs are difficult to implement if year-to-year continuity of monitored field cannot be taken for granted.

The present agronomic monitoring study was conducted in the conditions of Southern Veracruz, where such limitations to the conduct of "ideal" agronomic monitoring prevailed. Regional *Mucuna* extension efforts had begun just 3 yr prior to the study. The number of regional farmers intercropping *Mucuna* with maize was limited in general, and especially within any given village. Great variability characterized management and environment both between and within fields, and farmer adoption of the GMCC technology was changing and uncertain.

Why, then--it could be asked--should observational agronomic studies on GMCC systems be conducted in these diverse and variable environments where adoption is uncertain and research risky? Why should the researcher not focus attention only on the time-tested technologies which are easier to study, and from which the factors impacting performance and farmer adoption can be elucidated? The answer to this is that by continuously assessing technologies as they are being promoted, researchers are able to learn from the diverse experiences of their practitioners, and thereby continually refine their research agendas to fit the real, farm-level issues. At times, such a learning process may require studying technologies that are not being successfully adopted by farmers, and where the researcher is therefore certain to face methodological constraints such as those listed above.

CHAPTER 3

THE CONTEXT OF THIS STUDY: ENVIRONMENT, MAIZE FARMING, AND MAIZE-*MUCUNA* SYSTEMS IN LOS TUXTLAS

Introduction

Though *Mucuna* was spontaneously adopted by smallholders in the region of Los Tuxtlas in the 1950s, its adoption remained limited for decades. At the time of the *Mucuna* introduction, much of the Los Tuxtlas region was uninhabited forestland, a renowned reservoir of vast biological diversity. Most of the *Mucuna* adoption was by farmers located in a few villages in the Sierra de Santa Marta region, notably Mecayapan.

It was not before the 1990s, and only through a concerted effort by a Mexican NGO involving on-farm experimentation and extension, that a large number of local smallholders became knowledgeable about the utilization of *Mucuna* and began to cultivate *Mucuna* in their fields. In that 40-yr interval, the Los Tuxtlas environment had markedly deteriorated, due mainly to greatly increased population, deforestation, and cattle ranching (Ramirez et al., 1997; Guevara et al., 1997). The *Mucuna* extension efforts came about as a response to the problems that were seen to afflict maize (*Zea mays* L.) cultivation – the base of the rural population's subsistence in the area.

Farmers and researchers have experimented with several kinds of maize-*Mucuna* systems in the Los Tuxtlas region. Much of the initial on-farm experimentation and extension efforts, as well as the subsequent farmer adoption, focused on relay intercropping *Mucuna* in summer maize at mid-season (Buckles and Arteaga, 1993; Buckles and Perales, 1995; Arteaga, 1997). *Mucuna* was then either slashed to plant winter maize (hereafter “System A”) or left to mature in the field with no winter maize cultivation (hereafter “System B”). Though some of the early farmer adoption of *Mucuna* in the region had focused on a rotational system where *Mucuna* is sole-cropped over the summer and slashed prior to winter maize planting (hereafter “System C”), such a system was discontinued during the experimentation due to poor farmer interest (Buckles and Perales, 1995). Similarly, another system previously adopted in some villages had involved fallowing fields with *Mucuna* for several years; farmer experimentation with such system was not encouraged in the on-farm experiments due to the long time required to monitor its impact. In the final system that has received researcher interest, *Mucuna* is intercropped in summer maize, slashed prior to winter maize planting, and intercropped again in winter maize to benefit the following summer’s maize cultivation (hereafter “System D”).

The following discussion will begin with a brief overview of the Los Tuxtlas environment, outlining the biophysical and socioeconomic context in which the work on, and adoption of, the studied maize-*Mucuna* systems have developed. The discussion will then briefly introduce maize cultivation in the region, reviewing problems that afflict maize production among the region’s smallholders. The recognition of such problems was the impetus behind the *Mucuna* research and extension efforts in the region during the 1990s; these efforts will briefly be described. The second part of the discussion will detail current maize management systems and practices in the study area and describe those maize-*Mucuna* systems that are part of this study. The chapter will conclude with a discussion on the focus of this research.

The Environment of the Los Tuxtlas Region

Location and Major Landmarks

The Los Tuxtlas region is located in the southern part of Veracruz state at 18°10'N to 18°45 'N, and 92°42 'W to 95°27'W (Dirzo et al., 1997). Bordered by the Gulf of Mexico to the northeast, this mainly rural region encompasses an area approximately 78 by 40 km (Figure 3-1). Of volcanic origin, the area is undulating to mountainous, with altitudes ranging from 200 to over 1700 m. Five mountains reach a height of more than 1000 m.a.s: San Martín Tuxtla (1700 m), Santa Marta (1650 m), San Martín Pajapan, Cerro Pellón (1200 m), and Cerro Campanario (1180 m) (Soto and Gama, 1997). In the middle of the region is situated Lake Catemaco, Mexico's fourth largest lake.

The large towns of San Andres Tuxtla, Santiago Tuxtla, and Catemaco are located within the region; as are a large number of smaller municipal centers. To the south, lying just outside of the region, the petroleum cities of Coatzacoalcos, Minatitlán, and Jáltipan, as well the cattle-ranching city of Acayucan are influential. The cities of Veracruz and Jalapa (the state capital) are located to the north of the Los Tuxtlas area.

This study was conducted in the villages of La Candelaria and Santa Rosa Sintepec, near the town of Catemaco; the villages of San Pedro Soteapan and San Fernando in the area of Sierra de Santa Marta; and the village of Salto de Eyipantla, near the town of San Andres Tuxtla (see Figure 3-1).

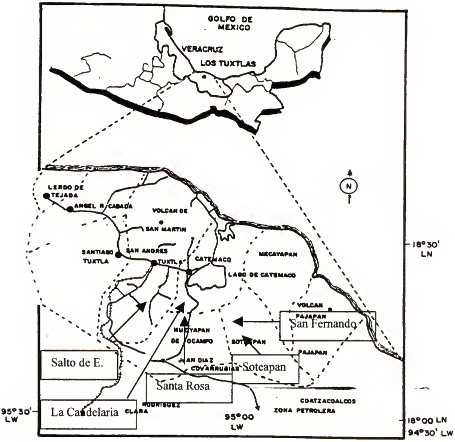


Figure 3-1. Location of municipalities and study villages in the Los Tuxtlas region.

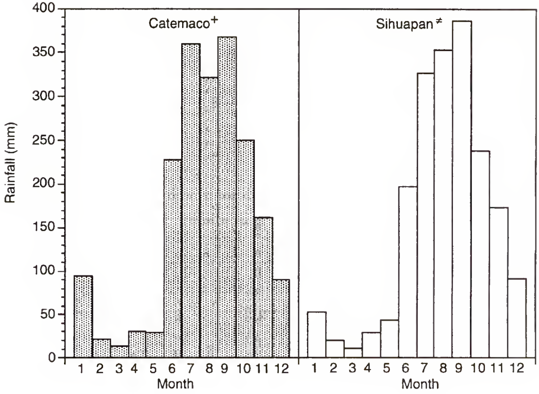
The Region's Climate

Due to the mountainous terrain, there is great climatic variability in the region. The average annual temperature is between 22 and 26°C. The highest daily extreme temperatures, typically from 34 to 36°C, are usually found in May, while lowest extreme temperatures, typically from 14 to 16°C in altitudes of 200 to 500 m.a.s, occur in January. Altitudes above 1600 m.a.s. can be classified as temperate, as their annual average temperature is less than 18°C (Dirzo et al., 1997). The general wind direction in the summer is from the north, while in the winter it is from the south. Tropical storms, especially those from the Caribbean, bring increased rain especially in September and in October. From October until March the region is affected by the "nortes" – northern winds from the United States and Canada that sweep across the Gulf of Mexico, bringing rains and low temperatures.

Due to the humid winds from the Gulf of Mexico and the impact of the mountains, the total annual rainfall varies greatly within the region, from 1200 to more than 4000 mm. The summer rains typically start in June. The months with highest rainfall are July, August, and September. In August, in a period called "canicula," there is typically a slight decrease in the monthly rainfall. The monthly rainfall begins to decrease in November and December and between January and May is greatly reduced. The maximum daily rainfall can be considerable, averaging over 100 mm in the coast. Figure 3-2 depicts average rainfall for two locations in the area, Catemaco and Sihuapan.

The Region's Soils

The region's soils are variable, and have not been studied in a detailed way (Tasistro, 1994). Relatively fertile Andepts are found in altitudes over 500 m, and in the area northeast of volcano San Martín. Alfisols are found to the west, east, and south of the Santa Marta and San Martín Pajapan volcanoes; they are slightly acid, have medium organic matter, are very low in P and in exchangable K, Ca, and Mg. Ultisols dominate areas north of the two volcanoes, and are of medium acidity, organic matter, and exchangeable cation content. Their P content is low. At low altitudes and the coast, lightly acidic Vertisols can be found; while at the coast Entisols are also found (INEGI, 1984; Tasistro, 1994).



+ Based on calculated average of monthly rainfall measurements between 1/1987 and 4/1997 obtained from the local weather station. No data was available for the following months: 1/1998, 9/1990, 1/1992, 4/1995 4/1996.

≠ Based on calculated average of monthly rainfall measurements between 1/1990 and 3/1997 obtained from the local weather station.

Figure 3-2. Average monthly rainfall in Catemaco and Sihuapan, Veracruz, 1987 to 1997.

Natural Resources

The Los Tuxtlas region is renowned for its natural beauty, with its forest-covered mountain slopes, undeveloped coastline, and undulating volcanic hillsides blanketed in ranches and maize fields, all cradling scenic Lake Catemaco in their midst. The great geographic diversity of Los Tuxtlas has been associated with a corresponding diversity in vegetation and species. The region hosts 14 vegetation types, and is home to more than 1149 animal species; 21 of them endemic (Ramirez, 1991; Ramirez et al., 1997). This natural resource base has, however, greatly suffered in the last decades. In the least developed part of the region, in the Sierra de Santa Marta area, forest cover in 1991 was only 45% of what it was in 1967 (PSSM, n.d.). Deforestation is attributable to the expansion of cattle ranching into the region and to population growth, both endemic and due to in-migration (Chevalier and Buckles, 1995). The relative accessability of Los Tuxtlas has made it particularly affected by such developments (Alvarez-Buylla Roces et al., 1989).

Socioeconomic Characterization

The region has been the site of major maize-based civilizations since Olmec times; maize has been cultivated locally for over 4000 yr (Buckles and Chavelier, 1995). Today, it is inhabited both by mestizos and by indigeneous people. The latter are mainly of Nahua and Popoluca origin residing primarily in the Sierra de Santa Marta area. A great majority of the region's inhabitants are devout Catholics; in addition, small Protestant groups can be found virtually in every village. Farming forms the base of subsistence for most of the rural people; on the sea coast, fishing predominates. Maize is the subsistence crop in the region, cultivated by a large portion of smallholders. Minor crops include beans (mainly *Phaseolus vulgaris* L.), groundnuts (*Arachis hypogaea* L.), choyote (*Sechium edule* Swartz), cassava (*Manihot esculenta*) and various fruits, as well as coffee (*Coffea* L.) in the higher elevations. Cattle ranching, practiced both by smallholders and by city-dwellers using hired labor, and dairy farming predominate in some parts of Los Tuxtlas. Tobacco (*Nicotiana tabacum* L.) is farmed by large landowners in the area between San Andres Tuxtla and Catemaco.

Poverty in the region is widespread. Only a portion of inhabitants have completed primary school (50% in the Sierra de Santa Marta region) and health problems afflicting the intestinal tract and skin are common (PSSM, n.d.). Cholera epidemics have become annual events since the mid-1980s. Smallscale farmers of the region have clearly remained largely untouched by the post-war economic 'Mexican miracle.' They have greatly suffered during the current economic crisis due to the stagnation of maize prices at a time when the price of inputs and general goods have been increasing.[2]

The region's rural people typically live in tightly-clustered villages. Most villages have an elementary school (at times also a secondary school), a clinic, a Catholic church, and a meeting house for the members of the *ejido*, the association of producers with rights to use collective land. Houses are made of wood or, less commonly, cement. Traditional palm roofs are still seen, but have given way to tin, while dirt floors predominate.

The traditional landowning patterns were largely based on the institution of communal land holding, *ejido*, to which most adult males belonged as *ejidatarios*. The institution regulated the members' access to land, which could not be sold. In at least one of the area's villages (San Fernando) the *ejido* institution existed formally, but in fact families operated their lands as if they were private; consequently land was bought and sold. In recent years, the land-owning has been privatized in most of the region's villages. Though the *ejido* institution continues to function in a limited form, its members have now private land titles and consequently can buy and sell land.

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[2] During the course of this research (1995 to 1997), the price of a bag of urea (50 kg) increased from 58 to 120 pesos, the price of beans from 4 to 6 pesos kg^{-1}, and the price of sugar from 5 to 8 pesos kg^{-1}. In contrast, maize prices stagnated at around 1 to 1.3 pesos kg^{-1}, while average salary from daily labor in the villages increased from 20 to 30 pesos.

Within a household, the division of labor is typically by gender. Men do most of the work in the fields, while women are responsible for the housework and cooking, including the laborious preparation of tortillas. However, women do contribute work in the fields, especially at the busiest times such as planting and weeding. Women seemingly participate more in the farming activities in Popoluca villages as compared to mestizo villages.

Challenges to Maize Farming

The traditional *milpa* cultivation system, commonly consisting of maize together with 10 to 20 other crops grown during the year's cycle, has all but disappeared (Stuart, 1978). However, maize farming largely continues to employ traditional practices including residue burning, use of traditional maize varieties planted widely spaced, reliance on labor inputs, and the utilization of simple tools, such as the machete and dibble stick.

Environmental conditions in most of the study region's villages allow the cultivation of two maize cycles: *maíz temporal* (hereafter referred to as "summer maize") and *maíz tapachole* (hereafter "winter maize"). Summer maize is the main crop due to the more favorable environmental conditions. Summer maize yields in the study villages are low; estimates in the literature have suggested 1.2 t ha^{-1} as an average yield (Buckles and Erenstein, 1996). In some areas the average may be even lower. Average winter maize yields have been estimated at 500 kg ha^{-1} (Buckles and Erenstein, 1996); however, such estimates may be somewhat high. Winter's low and erratic rainfall, high winds (either hot southern winds or northerly winds associated with cold fronts), and greater damage by birds have been cited as reasons for the lower yields in the winter growing season.

These low yields represent a significant decline from historical production capacity. It has been estimated that in the past 40 yr regional soils cultivated with maize and beans have lost 70-75% of their fertility (Tasistro, 1994 citing Uresti et al., 1993). As mentioned earlier, there has been a simulataneous decline in the cultivation of other crops as well, notably beans (Paré et al., 1994; Buckles and Erenstein, 1996).

Several important trends in recent decades have been linked to this dramatic decline in maize productivity. Perhaps most importantly, rising population pressure has forced traditional fallow periods to become shorter and less frequent. Traditionally, fallow periods were 8 yr, followed by 2 yr (3-4 cycles) of cultivation (Stuart 1978), but they have now declined to 2.6 years on average (Soule, 1997). Continuous or almost-continuous cropping has also become commonplace. Shortened fallows have resulted in decreased soil fertility and increased weed pressure. For a period of time in the 1980s and early 1990s, it seems that use of inorganic fertilizers compensated to a limited degree for the shrinking fallows. In a survey conducted in 1993, 60% of smallholders utilized fertilizers due to credit programs and assistance available to them (Soule, 1997). The economic crisis of the recent years has seen the discontinuation of many credit programs and increased prices of fertilizers. In contrast, the use of herbicides – typically Paraquat – has continued to be widespread. Herbicide use, in addition to the decline in soil fertility, would appear to account for the great reduction in the diversity of crops that can be grown in the field (Paré et al., 1994; Buckles and Erenstein, 1996).

Pest pressure on maize has reportedly increased (Buckles and Arteaga, 1997); a trend that the area's farmers often comment on. Major maize pests in the region are *Spodoptera frugiperda*, *Diatraea* spp., *Aenolamia* spp., *Phyllophaga* spp., and *Ortogeomis hispidus* (Buckles and Arteaga, 1997).

These mounting challenges to maize production in the region represent a relatively recent and drastic change in the smallholder's environment. They feature prominently in discussions with middle-aged and older farmers, who have seen these changes in their lifetime.

Research and Extension Efforts on *Mucuna* in Los Tuxtlas

The recent promotion of *Mucuna* in the region stemmed from the recognition of these problems by a group of individuals working in the region. The prime mover behind such efforts was the Proyecto Sierra de Santa Marta (PSSM), a non-governmental organization established jointly in 1990 by the Mexican Instituto de Investigaciones Sociales (the Institute of Social Research) of Universidad Nacional Autónoma de México (UNAM; the National Autonomous University of Mexico), Carleton University, and Canada's International Development Research Centre (IDRC; Buckles and Arteaga, 1993; Arteaga, 1997). Based in the state capital, Jalapa, the organization has been involved in the promotion of sustainable livelihoods through work in agriculture, forestry, horticulture, and fisheries in the region. The International Maize and Wheat Improvement Center (CIMMYT) participated actively in the organization's *Mucuna* research and extension efforts which began in 1991. From 1994, another NGO, Desarrollo Comunitario de Los Tuxtlas (DECOTUX; Community Development of Los Tuxtlas) conducted *Mucuna* extension campaigns in the San Andres Tuxtla area (Robles and Almeida, 1998) while the governments' Secretaría de Agricultura, Ganadería y Desarrollo Rural (SAGAR; Ministry of Agriculture, Livestock and Rural Development) organized extension campaigns on *Mucuna* in the region as well. Though this study was conducted in one village where DECOTUX was conducting *Mucuna* extension (Salto de Eyipantla), the impetus for the beginning of this research came from the efforts of PSSM, which are described in the following.

The efforts on *Mucuna* involved both research, which began in 1991, and extension, starting in 1992. This work clearly drew inspiration from the spontaneous adoption of maize-*Mucuna* systems in the region. Mounting international experience with *Mucuna* cultivation seemingly also acted as an impetus. In the following, a brief overview of such efforts is given.

On-farm Trials

In the summer of 1991, farmer-managed, on-farm experiments were initiated by two researchers involved with PSSM and CIMMYT. Such trials involved comparison of traditional maize cultivation without *Mucuna* to several maize-*Mucuna* systems (Buckles and Perales, 1995). These trials took place during two summer and two winter cycles. Each participating farmer chose one of the maize-*Mucuna* systems introduced to them, and planted it together with the control. The investigators concluded that in the short term, yield increases from the intercropped systems may only be expected in fields where winter maize is planted (System A), while residual yield effects in summer maize might become evident only after several years of *Mucuna* intercropping. Farmers familiar with *Mucuna* in the region evidently agreed that *Mucuna* is "best for winter maize" (Buckles and Perales, 1995).

Extension Efforts

The extension efforts in the region started in 1992, only 1 yr after the initiation of on-farm trials, and therefore before any impacts on summer maize could have been detected. This short interval could perhaps be explained by two factors: an understandable desire to quickly present potential solutions to problems that afflict maize farming in the region and the general world-wide enthusiasm for the potential of GMCCs, especially *Mucuna*. Extension began in April 1992, when the Proyecto Sierra de Santa Marta held a meeting to explain research results from the previous year to regional farmers. Seven of these farmers were asked to hold meetings in their respective villages, and were later hired as village-level farmer-extensionists (*promotores*) by the project. Typically, *Mucuna* and its various uses were introduced in village meetings, after which 1.5 kg of *Mucuna* seed was offered at no cost to each farmer willing to plant. It is estimated that in 1992-93, 2250 people in over 45 villages were reached through the meetings; of them 1164 accepted *Mucuna* seed (Buckles and Perales, 1995, Arteaga, 1997). To solicit information from farmers and to observe maize and *Mucuna* growth, almost one-fourth of those planting *Mucuna* were visited by the farmer-extensionists during the subsequent 2-yr period.

Further demand for *Mucuna* seed resulted from the ongoing extension campaign. Altogether, over 5 t of *Mucuna* seed were purchased from the farmers in the region, and distributed between 1992 and 1993 (Buckles and Perales, 1995).

After 1994, the efforts expended on *Mucuna* extension decreased. In 1995, a relatively large number of farmers, two to three thousand, were estimated to be utilizing *Mucuna* in the region. However, my reconnaissance visits at the beginning of this study in 1995 suggested a more limited number of farmers growing *Mucuna*, on the order of hundreds. Most of the farmers that were utilizing *Mucuna* utilized System A or System B; the latter was more popular. While this study continued to pursue its proposed objectives that were of an agronomic nature, the trend of declining *Mucuna* use naturally introduced an additional dimension to the study. Dwindling numbers of maize-*Mucuna* cultivators of course made it more difficult to execute this study. It can, however, be argued that the evident disinterest in *Mucuna* use added further importance to this study: Could the field-level monitoring and on-farm trials of this study perhaps provide answers on the agronomic reasons behind the disinterest?

Of note: In 1998, *Mucuna* cultivation in the region has reportedly once again increased. Government's Secretaria de Medioambiente, Recursos Naturales y Pesca (SEMANARP; Ministry of Environment, Natural Resources and Fisheries) will be buying large amounts of seed from farmers affiliated with the two NGOs that are currently working in the region (L. Arteaga, personal communication).

Maize Management Practices

Maize Cropping Patterns

Three major regional patterns of maize cultivation can be distinguished, based on use of the summer and/or winter growing seasons. The choice of cropping pattern depends partly on the local environment, because conditions in some locations, typically those in higher altitudes, prevent winter maize planting. In other areas, typically in the lowlands, winter maize growth is favored and is planted almost as much as summer maize. The choice of cropping pattern also depends in part on the resources available for the farmer, including the type of available land, labor, and inputs.

- *Summer maize only*: In most of the study villages, the largest amount of land is under summer maize only.
- *Summer maize followed by winter maize*: Winter maize is intercropped between rows of mature, doubled summer maize. Such practice is widespread, but minor, in that most farmers in the study region plant a small part of their fields in this way. For example, a farmer planting 2 ha of summer maize may only plant 0.5 ha of winter maize.
- *Winter maize only*: At times, farmers plant winter maize in an area where no cropping had taken place over the summer season; such area may have been fallowed for a longer time. This practice is less common.

Minor intercrops introduce additional variability to these systems. For example, in a part of the field beans may be intercropped in summer maize in early September;

other intercrops (e.g., choyote) are seen at times. Beans may also be sole-cropped in June, and winter maize may follow.

In the following, the management of maize in the region is described based largely on maize management as observed in the five study villages. Due to the variability in the region, not all details will apply to all locales in Los Tuxtlas.

Management of Summer Maize

Summer maize management extends through most of the year, from slashing in April to May until harvest in January to March.

Slashing and burning: In the study villages, preparations for summer maize planting begin with slashing, which takes place during the dry season, typically in April or May. Slashing time varies greatly, and can continue until June.

Slashing consists of cutting dried maize stalks and weeds in the field. Weed growth is often substantial, especially if no winter maize has been grown. If the field has been fallowed – a practice that is becoming more rare – typically the growth consists of shrubs and weeds; trees are very seldom present due to the brevity of fallow intervals. Farmers cut standing dried vegetation with a machete, typically aiding the work with a wooden stick held in the other hand. Slashing is the most arduous and labor-intensive of the maize management practices, and takes place during the hottest and driest part of the year.

Once all the slashed vegetation is considered dry, the farmers typically return to burn the fields. The practice of burning varies greatly among the study villages and farmers. Traditionally, a full burn has been used, in which all plant residues are left on the ground, and the fire is allowed to go through the vegetation. Of late, caution in the use fire has been urged; both to prevent fires that break loose with disastrous consequences, and to promote soil conservation. Consequently farmers, especially those in less remote villages, seem to utilize a less severe burn in which most plant residues are collected in heaps or alleys. Interviews with farmers suggest that such practice may be attributed in part to the lower residue-loading capacity in the region; i.e., the plant residues are no longer sufficient to support a full burn. Several farmers noted that they burn their field evenly if there is enough litter. If litter is not sufficient, they collect it together and burn the heaps.

Maize variety: Though farmers continue to plant mainly traditional varieties (landraces *Tuxpeño* and *Olotillo*), the diversity of maize varieties has been greatly reduced. Earlier, white, yellow, black, and red varieties were cultivated (Stuart, 1978). At the moment, almost all cultivation is of the white variety; rarely does one see yellow, black, or red varieties. Farmers typically indicate that the predominance of white maize is due to its marketability. Improved varieties are utilized by a handful of farmers.

Planting: Maize planting typically takes place in June, once the soil has been sufficiently moistened after the first rains. In the villages with high elevation (San Fernando in this study), and in years with very early rains, planting may occur as early as May, especially in the fields with the highest elevation and earliest rains. Almost all farmers utilize traditional planting patterns, leaving 0.8 to 1 m between alleys, and approximately 1 m between hills. Often, farmers make use of ropes tightened between sticks to aid in planting straight maize rows. A dibble-stick is used to create a hole into which typically three seeds are dropped, and the hole is covered with soil, using the heel.

Though typically planting is a one-person task, at times one person creates the holes while another drops and covers the seed. Weeding with a herbicide is typically conducted at the time of planting.

Weedings: Most farmers utilize herbicides for weeding and Paraquat is used most widely. At times, weeding is performed with either a machete or hoe. The first weeding is conducted 2.5 to 5 wk after maize planting. A second weeding is typically performed at 6 to 10 wk after planting. At times, an additional weeding is conducted just prior to doubling.

Doubling: Maize is doubled at physiological maturity; typically in late September or early October. Doubling consists of bending the maize stalk below the ear; thereafter the maize ear points downwards. Typically three explanations are given for this practice: to prevent lodging from winds, which become increasingly common during the winter season, to aid with drying of the ears, and to prevent damage from birds.

Harvest: Some harvesting takes place as green maize; such quantities are minor and intended mainly for home consumption. Additional maize is harvested throughout the fall when needed for home consumption. Typically, maize is left standing in the field until February or even March; such a practice is said to be done to avoid the high post-harvest losses commonly accrued if maize is brought home. In some villages (in Salto de Eyipantla in this study) harvesting is conducted early to prevent the theft of maize. At harvest, the husk is removed from the ears manually, and cobs typically are thrown into heaps on the ground or placed in sacks. Sacks of harvested ears are either carried to the village or transported by a horse or a donkey. Once harvested, a portion of maize may be sold; the remainder is stored at home.

Management of Winter Maize

If a winter maize crop is desired, it will typically be planted in the alleys between the doubled summer maize. At times, a field that has been fallowed for one summer or longer will be slashed, perhaps even burnt, and winter maize will be planted thereafter. The following discussion outlines winter maize management in the usual situation, where winter maize is planted in summer maize fields.

Winter maize planting typically takes place in the first days of November; delayed planting is risky since rainfall becomes lower and more erratic with the advancing growing season. In late October or early November, fields are either slashed or at times, merely weeded with a herbicide. Such preparation may be done anywhere from weeks to days before planting. Winter maize is planted in the manner of summer maize, but in the middle of the summer maize alleys. Due to lower rainfall in the winter, typically only one weeding is required, and the maize does not need to be doubled.

Winter maize is typically harvested in April.

Systems of Maize-*Mucuna* Production

As discussed earlier, there was some traditional use of *Mucuna* in the region before the initiation of the on-farm experimentation and extension with *Mucuna* in the early 1990s. Buckles et al. (1994) estimate its extent to be about 300 farmers in various villages; seemingly such cultivation goes back to the 1950s. Three systems of maize-*Mucuna* were practiced by these farmers, two of which were not particularly intensive (Buckles and Perales, 1995). In one, *Mucuna* was oversown in fields that were left fallow. Another system was rotational involving sole *Mucuna* cultivation during the rainy summer season; after it was slashed, winter maize was planted. A third, more intensive but less common system involved relay intercropping *Mucuna* in summer maize.

As environmental and management variability in the region of Los Tuxtlas is high, the following description applies to maize and *Mucuna* production as it was observed in the five villages included in the study. More in-depth description of these systems, based on the results of agronomic monitoring and on-farm experimentation, is found in Chapters 4, 5, 6, and 7.

On the whole, the extension efforts of the 1990s mainly promoted two maize-*Mucuna* systems that intensify land use as compared to the traditional systems (Buckles and Barreto, 1996). In both systems, *Mucuna* is intercropped in summer maize (Table 3-2). In System A, *Mucuna* is slashed prior to winter maize planting, while in System B it is allowed to mature in the field. The monitoring and experimental portions of this study collected data on both Systems A and B. In the experimental portion of this study, two additional systems were investigated – both of which had precedents in the region. The traditional rotational system, summer cultivation of only *Mucuna*, followed by a sole crop of winter maize, is labeled "System C" here. The intensive System D is identical to System A, but with a *Mucuna* intercrop in the winter.

In the following, the management of the maize-*Mucuna* systems is described in detail; Table 3-1 and Figure 3-3 provide a comparison of the seasonal cropping patterns in each system while Figures 3-4, 3-5, 3-6 and 3-7 provide photographic illustrations of the systems.

Maize-*Mucuna* System A

In System A, *Mucuna* is intercropped in summer maize typically in August, from 40 to 90 d after maize planting. *Mucuna*'s planting often follows the second maize weeding, but at times an extra weeding is conducted just prior to *Mucuna* planting. *Mucuna* is planted between maize rows with a dibble-stick in a fashion similar to maize planting. Extension efforts recommended planting at a hill density similar to maize, but at only two seeds per hill. Most commonly, white and/or mottled *Mucuna* seed types are used.

Table 3-1. Maize-*Mucuna* systems in this study.

Maize-*Mucuna* System	Summer	Winter
System A	Maize/*Mucuna*	Maize
System B	Maize/*Mucuna*	*Mucuna*
System C	*Mucuna*	Maize
System D	Maize/*Mucuna*	Maize/*Mucuna*

In both of the intercropped systems (A and B), farmers typically plant intercropped *Mucuna* only in part of their summer maize. Typically, areas with *Mucuna* intercrop in the fields of this study did not exceed 1 ha, and were commonly less than 0.5 ha. Moreover, farmers often rotate the area under *Mucuna* within a field. Such rotation of crops is common with any crop grown in the field. In the case of *Mucuna*, farmers often indicate that they do this to "harvest" the benefits accrued from *Mucuna*.

Mucuna requires about 8 d to germinate. Due to the variability in *Mucuna* planting dates and maize variety, maize height at the time of *Mucuna* planting may be from 1 to over 2 m. From germination until maize doubling in late September to early October, *Mucuna* evidently suffers from shading by maize, and its growth is slow. Typically runners start developing, but remain thin and short, and only start the process of climbing up the maize stalks closest to them. After the maize doubling opens up the canopy, a favorable light environment enables a period of rapid *Mucuna* growth; in some fields, weeds also grow rapidly at this time. *Mucuna* then starts to climb over the doubled maize.

In System A, *Mucuna* is slashed prior to winter maize planting in late October or early November. At that time, *Mucuna* growth is relatively limited, consisting of growth in patches around the doubled maize plants. The *Mucuna* slashing practices are quite uniform: *Mucuna* and weeds are slashed into alleys between maize rows and then often slightly chopped. Often, some *Mucuna* stems and leaves stay wrapped around the maize stalks. Considerable variability exists in the thickness of the mulch created by *Mucuna* and weeds. Some farmers elect to harvest summer maize at that time if *Mucuna* growth is luxuriant, because slashing would be difficult with maize present. There is considerable variation in the time between slashing and subsequent winter maize planting, but farmers typically prefer to wait at least several days so that the mulch has collapsed. At that time, erratic rainfall may further delay planting. Typically, winter maize is planted 1 to 2 wk after *Mucuna* slashing.

The slashed *Mucuna* decomposes with relative rapidity with the continuing rainfall of November and December. By the time of maize flowering in late January and February, in many fields evidence of prior *Mucuna* in the fields is detected only in patches.

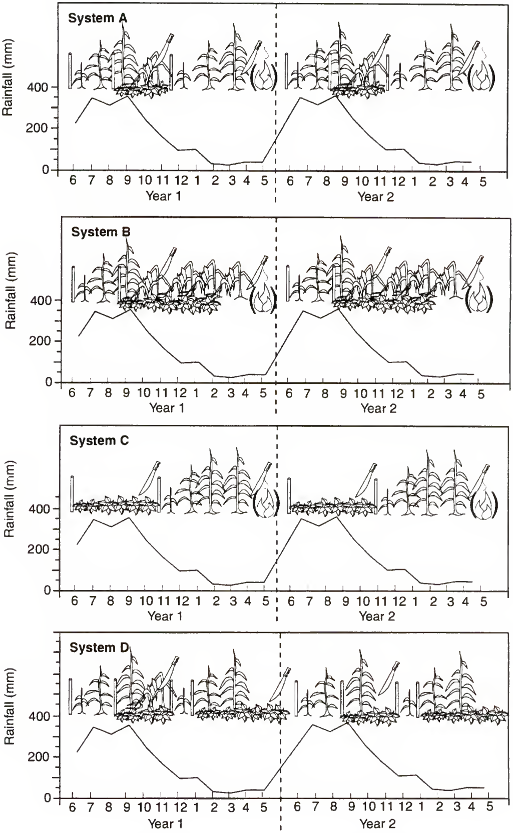

Figure 3-3. Seasonal cropping patterns of maize-*Mucuna* systems in Los Tuxtlas.

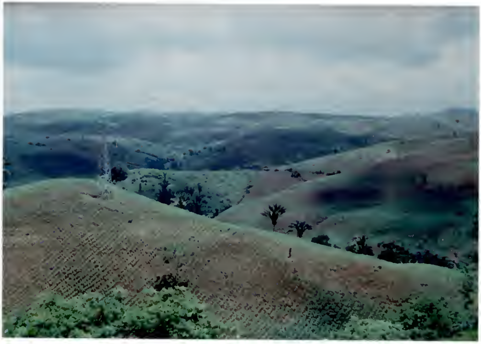

Figure 3-4. A typical smallholder cropping zone in the study area, showing predominance of maize cultivation and sparsity of forest cover.

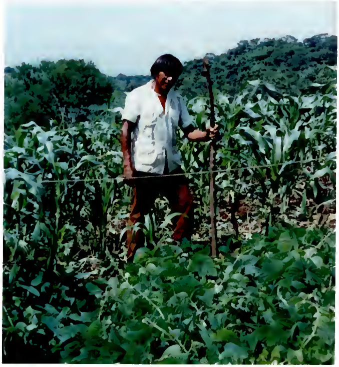

Figure 3-5. *Mucuna* being intercropped in summer maize in August (System A or B). June-planted, sole-cropped *Mucuna* in the foreground (System C).

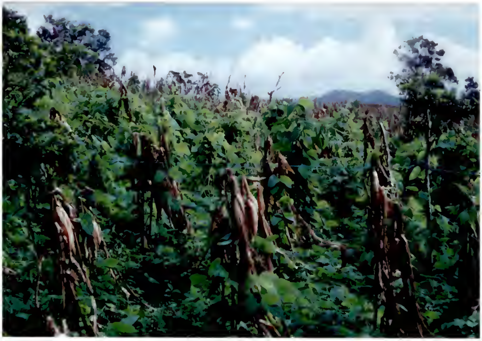

Figure 3-6. August-planted, intercropped *Mucuna* growing over doubled maize in late October (System A or B).

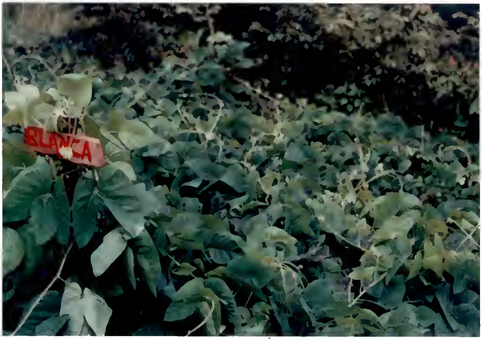

Figure 3-7. June-planted, sole-cropped *Mucuna* in late October just before slashing (System C).

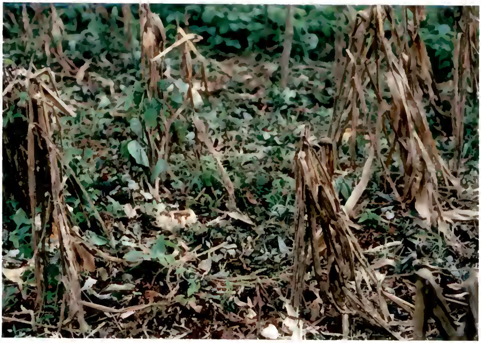

Figure 3-8. Mulch cover following the slashing of *Mucuna* in early November (System A).

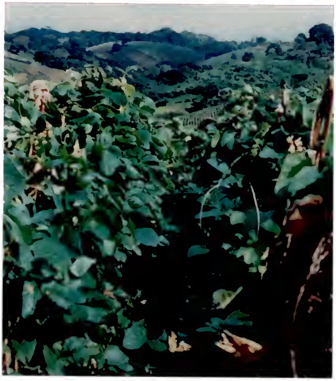

Figure 3-9. Relatively good *Mucuna* growth in December under System B conditions.

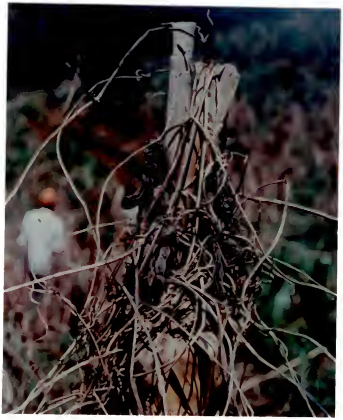

Figure 3-10. Dried *Mucuna* stems and pods wrapped around maize stalks in April (System B).

Figure 3-11. The author fondly acknowledges the contributions of the study's cooperating farmers.

Maize-*Mucuna* System B

The management of maize and *Mucuna* in System B is identical to that in System A until the time of *Mucuna* slashing. In System B, *Mucuna* is not slashed at the end of the rainy season, but is allowed to grow in the fields. Typically, by early December, *Mucuna* is flowering and forms bushy growth around the doubled maize stems, not fully covering the ground. In some fields, near complete ground cover is achieved before senescence; in most it is not. Weeds occupy a varying amount of field area.

Mucuna typically attains its maximum growth in early January. Senescence follows quite rapidly thereafter, and by early February *Mucuna* in most fields has senesced. Annual variation in the time of senescence seems to occur. Senescence can start as early as late December if conditions are very dry. Moreover, in the higher-altitude villages with higher winter season humidity, *Mucuna* senescence is delayed.

In this intercropping system, *Mucuna* often sheds relatively few leaves before senescence, presumably due to the more favorable light conditions following maize doubling. With senescence, leaves fall and rapidly dry on the ground. Clusters of dried leaves form, either in places where they fall at senescence, or where they are blown by winds. *Mucuna* stems remain wrapped around the maize stalks. Between February and the usual slashing operation of April or May, no thick uniform mulch layer is evident over the soil. Rather, in large parts, the soil is bare, while in parts it is covered with standing weeds.

Only in patches is the prior *Mucuna* evident. Most *Mucuna* pods shatter seeds during the dry season. Farmers may collect seed after it has matured. Typically it is collected in pods, which are opened at home. Cattle or horses may graze in the fields prior to the slashing operation. After the rains, a part of the *Mucuna* seeds left in the fields germinate, potentially competing with maize.

Maize-*Mucuna* System C

As mentioned earlier, one of the spontaneously adopted regional systems was a rotational system of maize-*Mucuna* cultivation in which winter maize is planted following the cultivation of summer sole-cropped *Mucuna*. Relatively little detailed information is available on the farmer practices using this system. In the following, this "System C" is described as managed and observed under the experimental conditions of this study.

Mucuna is planted at the beginning of summer rains, at the same time as summer maize. Since it is planted under sole-cropped conditions and there is no competition with maize, planting can be done at higher densities than in systems A and B. Under experimental conditions, planting pattern and density were modeled after those of bean in the region, leaving 0.8 m between rows and 0.5 m between hills. Two seeds per hill were planted, resulting in a planting density of 50 000 plants ha^{-1}. In some fields with high weed pressure, *Mucuna* growth was seemingly greatly aided by a weeding conducted about 1 mo after planting, at a time when *Mucuna*'s growth is yet relatively limited, and selective slashing of weeds is an easy matter. Under System C conditions, by 2 mo after planting *Mucuna* has attained almost 100% ground cover in the fastest-growing fields, and is starting to shed leaves near the ground due to self-shading. At that time, *Mucuna* height can be 70-80 cm. By the late October slashing time, *Mucuna* has started flowering, and some young pods may have developed already. Slashing is conducted as in System A, but is less laborious since there is no summer maize in the fields that needs tending; also weed growth is limited. The slashed *Mucuna* typically forms an even, often thick, layer of mulch, into which winter maize is planted. Winter maize planting may be delayed since rains are often erratic at this time.

Maize-*Mucuna* System D

System D is the most intensive of the four systems included in this study, and includes two maize and two *Mucuna* crops. This system has been tried under experimental conditions only. It was included in the original farmer-managed trials in 1991 and was tried again in this study in 1995-96, but discontinued.

The management of this system is identical to System A management until December. At that time, a second *Mucuna* crop is intercropped in winter maize, at densities similar to the *Mucuna* intercropped in the summer. *Mucuna*'s early development is slow due to dry conditions. The hope in the trials was that *Mucuna* would overwinter and, with the beginning of summer rains, would quickly generate sufficient biomass. If summer maize planting could then be slightly delayed, such biomass could be slashed, and summer maize could be planted subsequently. This system was partially modelled on systems investigated by the TROPSOILs project (Lobo Burle et al., 1992).

The performance of this system was disappointing due to poor overwintering of *Mucuna* and it was therefore discontinued in the trial (see Chapter 6 for details on System D).

A Comparison of the Maize-*Mucuna* Systems

The four different maize-*Mucuna* systems in this study differ in several important aspects (Table 3-2):

- In their cropping pattern: *Mucuna* is intercropped in Systems A, B, and D, while in System C *Mucuna* is sole-cropped;
- In their growing period: The *Mucuna* growing period is relatively short in Systems A and during the fall cultivation in System D. In contrast, growing periods are lengthy in Systems B, C, and winter-spring cultivation of D.
- In rainfall during *Mucuna* growth: *Mucuna* grows under high to intermediate rainfall conditions in System C, whereas in the other systems *Mucuna* grows under intermediate to low rainfall conditions. During the winter cycle in System D, rainfall is very low during most of the growing period; as mentioned earlier, the feasibility of the system is questionable.
- In the maize crop that they mainly benefit: In systems A and C, *Mucuna* slashing is followed by winter maize planting, which it mainly benefits. System D was designed to benefit both winter and summer maize. System B can be expected to mainly benefit summer maize, since *Mucuna* drying is followed (after a timelag of up to half a year) by summer maize planting.
- In their association with burning practice: No burning of *Mucuna* mulch immediately after the growing period takes place in Systems A, C, and D, while *Mucuna* mulch is commonly burnt in System B.

- In their ability to produce seed: In Systems A, C, and D, *Mucuna* is slashed when immature; no significant quantity of seed can therefore be produced. In System B, *Mucuna* matures and produces seed.

Finally, this study generated different types and quantities of data on the four systems. Systems A and B were covered most thoroughly, as they were included both in the monitoring and in the experimental components of this study. Systems C and D were included only in the experimental component of the study. Relatively little data are available on System D, as it was only included in one trial for 1 yr due to its poor performance.

Table 3-2. Characteristics of the maize-*Mucuna* systems included in this study.

Characteristic	System A	System B	System C	System D
Cropping pattern	Intercropped	Intercropped	Sole-cropped	Intercropped
Approx. *Mucuna* growing period (mos)	2.5	5	4.5	2.5 6
Rainfall during *Mucuna* growth†	H/IM	H/IM/L	H/IM	H/IM L/IM
Maize crop principally benefitted	Winter	Summer	Winter	Summer & winter
Residue burning	No	Yes/No	No	No
Seed production	No	Yes	No	No

† H=High; IM=Intermediate; L=Low

The Focus of This Study

The environmental and historical background of this study is described above to help the reader understand the context of this study. It explains the focus of the study, the farmer-practiced Systems A and B, and alternative Systems C and D, only in the most general terms. Such systems could clearly be studied from a variety of viewpoints, from agricultural policy to soil microbiology. Previous research on the maize-*Mucuna* systems in the area had assessed these systems from an economic viewpoint (Buckles and Erenstein, 1996; Soule, 1997). During the latter part of this study, the maize-*Mucuna* systems in the region were the focus of an inter-institutional evaluation of GMCCs in Southeastern Veracruz (Arteaga et al., 1997). This study's orientation was that of crop management and its focus was limited to the productivity of maize and *Mucuna* in the above-described systems.

A simplified diagram (Figure 3-12) was constructed to help demarcate the focus of this study.[3] Such a diagram describes the scope of this study in the framework of the implicit objective of work conducted on the maize-*Mucuna* systems: impact in the regional level in terms of productivity, sustainability, and well-being of the farming families. The diagram depicts the context in which this study took place, and also explicitly demonstrates its acknowledged limited scope. This study had a very limited focus, in that it proposed to quantify some of the factors associated with *Mucuna* growth and *Mucuna*'s impact on maize. However, it could do so only from a comparative perspective, by comparing fields with different management factors and different maize-*Mucuna* systems. Factors that overall favored or limited *Mucuna* growth or its impact on maize yield in the region could only be described qualitatively. Moreover, this study did not directly focus on the adoption of the maize-*Mucuna* systems in the region, though the agronomic performance does, of course, contribute to such use or adoption. Finally, no estimates of the impact of *Mucuna* use or adoption at regional level were made.

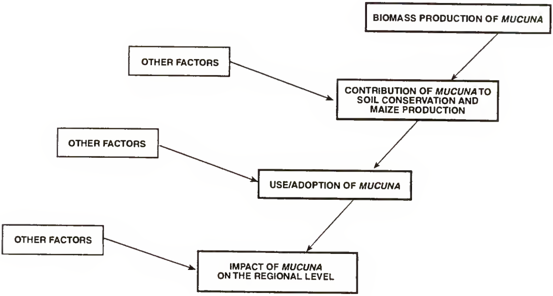
BIOMASS PRODUCTION OF *MUCUNA*
OTHER FACTORS
CONTRIBUTION OF *MUCUNA* TO SOIL CONSERVATION AND MAIZE PRODUCTION
OTHER FACTORS
USE/ADOPTION OF *MUCUNA*
OTHER FACTORS
IMPACT OF *MUCUNA* ON THE REGIONAL LEVEL

Figure 3-12. The conceptual context of this study.

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[3] A more complete diagram is presented in Appendix B, hypothesizing factors that impact *Mucuna* biomass production, its contribution to maize yields, as well as adoption of *Mucuna* in the region.

CHAPTER 4
AGRONOMIC MONITORING OF THE FARMER-MANAGED MAIZE-*MUCUNA* SYSTEMS: I. *MUCUNA* BIOMASS AND SUMMER MAIZE YIELD

Introduction

Starting in the 1970's, and increasingly in the 1980's, researchers working to increase food production and prevent resource degradation among tropical smallholders have turned their attention to agricultural systems utilizing green manure/cover crops (GMCC). By the early 1990's GMCC promotion efforts had begun in earnest worldwide, while the experimental work of the previous decades continued. A large number of diverse institutions, including research institutions and non-governmental organizations, concentrated their efforts on *Mucuna*, which by the 1990's had become the most popular of the GMCC species promoted in the tropics (Buckles, 1995). Almost a decade of such promotion efforts has now passed, and it has become clear that their success has been mixed. The lack of formal evaluation of these technologies and promotion efforts is striking. Specifically, the agronomic performance of the promoted systems has received very little attention from agricultural researchers. Few *ex post* studies on the GMCC species' on-farm productivity and performance have been done (Carsky et al., 1998).

In the Los Tuxtlas and Sierra de Santa Marta regions, the adoption and farmer cultivation of *Mucuna* was not well established in 1995, the year of the initiation of this monitoring. As reviewed in Chapter 3, the initial regional *Mucuna* extension efforts had started in 1992. Though *Mucuna* was reported to increase maize yield in the region, no agronomic assessment had been conducted. Three years after the beginning of the extension efforts, it was determined that such assessment was needed to determine the performance of maize and *Mucuna* in the system and of the factors impacting such performance. To meet this objective, this study proposed to do the following:

- Characterize quantitatively the field conditions (both management and environmental) in which the adoption of the maize-*Mucuna* system had taken place;
- Quantify the productivity of maize (grain, kg ha^{-1}) and *Mucuna* (biomass, kg ha^{-1}) in the farmer-managed systems;
- Quantify the impact of key management and environmental factors affecting the productivity of maize and *Mucuna* in the farmer-managed systems;
- Quantify the impact of *Mucuna* on productivity of maize in the farmer-managed systems; and
- Evaluate and develop the methodology of agronomic monitoring.

The research design and analysis were based on a hypothetical experimental design. For maize yield, "treatments" consisted of maize grown in plots with and without the *Mucuna* relay intercrop. For *Mucuna* biomass production, "treatments" consisted of the two maize-*Mucuna* systems (A or B) practiced by the farmers in the study area.

In this chapter, methods employed in the monitoring are presented, as well as results on maize yield, *Mucuna* biomass production, and factors affecting them in farmer conditions. Chapter 5 focuses on *Mucuna*'s impact on maize yield in the monitored fields.

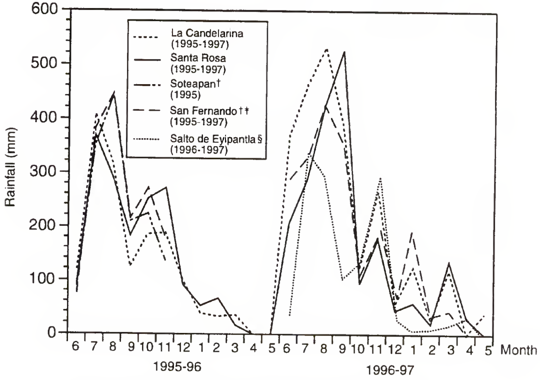
Materials and Methods

Agronomic monitoring of farmers' fields was conducted during the summer maize (*maíz temporal*) cycles in 1995 and 1996. The monitoring took place in five villages and included a variable number of fields (4-12) per village. Four monitoring plots were situated in each farmer-managed field: two plots where the farmer was intercropping *Mucuna* with maize, and two plots where the farmer was cultivating maize alone. Since farmers seldom intercropped *Mucuna* over a whole field, the two sets of plots could usually be located in the same field. The monitoring focused on the growth of maize and *Mucuna*, and on the factors that affect their growth. Periodic visits and one-time measurements constituted the core activities of the monitoring program. Additional information from farmers was solicited during home and field visits. A general description of the environment in the study area and the maize-*Mucuna* systems studied is covered in Chapter 3.

Rainfall in 1995 and 1996

In 1995, the rains began approximately 10 d to 2 wk late. Rainfall during the summer season was normal, but the winter season was unusally dry (Figure 4-1). Dry weather, cool nights, and hot day temperatures presumably had a negative affect on maize and *Mucuna* growth.

In 1996, the timing and quantity of summer rains were near normal. Winter rainfall in 1996-97 was unusually high and well-distributed, and some *Mucuna* germinating from seeds on the fields stayed green throughout the dry season.



† Rainfall measured only until summer maize harvest, 1995.
‡ Measurement started June 25, 1995
§ Measurement started June 26, 1996.

Figure 4-1. Rainfall in the study villages during the period of this research.

The Study Villages

The study was conducted in four villages in each study year 1995 and 1996. Three villages were studied across the 2 yr: La Candelaria, Santa Rosa Sintepec (hereafter Santa Rosa), and San Fernando. A fourth village, San Pedro Soteapan (hereafter Soteapan), was utilized in 1995; while a fifth, Salto de Eyipantla (hereafter Salto de E.), substituted for Soteapan in 1996. Monitoring was discontinued in Soteapan because it was feared that violent conflicts over land might erupt there, associated with the 1995-96 land privatization reforms.

Village selection

The study villages were selected during reconnaissance visits to the area in May and June of 1995. Potential villages were identified and initial contacts were made with the aid of the Proyecto Sierra de Santa Marta, the NGO that had led regional *Mucuna* extension campaigns. Where possible, the project's local farmer-extentionist was sought out. Otherwise, a farmer known to the project personnel was contacted. The study's purpose and plan were discussed with the contact person, and if enough farmers in the village were cultivating *Mucuna*, a meeting with the maize-*Mucuna* farmers was arranged to solicit farmer participation.[4] Generally, communities and farmers were receptive to the research project, and most farmers contacted wanted to participate in the study.

Final selection of the study villages was based on three criteria: an adequate number of maize-*Mucuna* farmers (at least six)[5]; location in relative proximity to one another (to satisfy logistical constraints); and, naturally, farmer cooperativity. Originally, to assess the impact of environment on the growth of maize and *Mucuna*, it was intended that each study village should represent a different growing environment. This objective had to be partially abandoned, however, as only a few villages were found that satisfied the first criterion, a sufficient number of *Mucuna* farmers. For this reason, two of the study villages (La Candelaria and Santa Rosa) are adjoining, and represent roughly similar growing conditions.

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[4] In 1996, no such initial farmer meeting was conducted in Salto de E., the village where monitoring was started that year. Rather, farmers were visited in their homes.

[5] In 1996, the monitoring was completed in fewer than six fields in San Fernando and Salto de E. due to the small number of farmers planting *Mucuna* that year.

Village characteristics

The monitoring was conducted in four villages each year. La Candelaria in the municipality of Catemaco, and Santa Rosa in the municipality of Huyepan Ocampo are located in a less-remote part of the Los Tuxtlas area and have mestizo populations. The farmlands of the two villages merge, thus creating a continuous environment, though resource-base and therefore cultivation practices seemingly differ in the two communities. San Fernando and Soteapan in the municipality of Soteapan are located in the more remote Sierra de Santa Marta region, and are either completely, as in the case of San Fernando, or predominantly, as in Soteapan, of Popoluca Indian origin. Though the distance between the villages is only 5 km, due to the higher altitude and lower population density of San Fernando, cultivation practices differ between the two villages. Salto de E. is a large semi-urban center in the municipality of San Andres Tuxtla.

The villages differ both in their environmental conditions and cultivation practices. In summary, Santa Rosa, La Candelaria, and Soteapan are relatively drier growing environments with relatively poorer soil fertility. Consequently, winter maize is a minor crop in the farming systems of these villages. San Fernando's higher soil fertility and rainfall allow for higher maize yields, but the winter season's high winds and relatively low temperatures generally make winter maize cultivation unfeasible. Salto de E.'s soils and rainfall distribution allow for two maize seasons.

Selection of Fields and Plots

Monitoring was completed in 38 fields in 1995 and in 26 fields in 1996. Sixteen fields were shared across the 2 yr. Some additional measurements on *Mucuna* mulch and seed density were made prior to summer maize planting in 1997.

Field selection

In the initial village meetings, individual questionnaires were used to solicit information on the history of and plans for that year's *Mucuna* cultivation. On the following day, the fields were visited with each farmer to make field maps indicating areas previously under *Mucuna* and the farmers' plans for *Mucuna* planting that year.

Little further field selection of any kind was possible. This was mainly due to the relatively small number of maize-*Mucuna* farmers in each village. For this reason, fields with both maize-*Mucuna* System A and System B were included in the study.[6] Though it was intended that one-half of the study fields would not have been burnt prior to summer maize planting, few fields with no burning were found. The decreased number of fields in 1996 was mainly due to declining farmer interest in *Mucuna* use; monitoring was discontinued in fields where farmers indicated that they would most likely not plant *Mucuna*.

Field characteristics

The selected fields therefore represent two different maize-*Mucuna* systems. They also differ in regard to the number of years that the farmer had planted *Mucuna* in the location of the *Mucuna* plots. Moreover, they differ in environmental factors, slope, and fertility. Finally, as discussed later, management of maize and *Mucuna* differed greatly from one field to another. Thus field characteristics were highly variable in this study, as evidence by Table 4-1.

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[6] Farmers do not always decide at the beginning of the summer maize growing season whether they will manage *Mucuna* according to system A or B. This also contributed to the inclusion of the two systems in the study.

Table 4-1. Proportion of fields represented by a management or environmental characteristic in 1995 and 1996.

	System		Residue burning		Sloping		Year of Mucuna planting		
Year	A	B	Yes	No	Yes	No	1st	2nd	≥3rd
	%								
1995	19	81	65	35	84	16	35	49	16
1996	32	68	66	34	72	28	8	50	42

Siting of plots

The study called for a paired comparison between maize plots with and without *Mucuna*. Two "no-*Mucuna*" plots were located in an area of the field where the farmer had never intercropped *Mucuna* with summer maize, and two "*Mucuna*" plots in an area where the farmer was going to plant *Mucuna* during the study year, and where he may have planted earlier. Plot size was 10 m by 10 m. Monitoring was completed in 152 plots in 1995 and in 103 plots in 1996.

The two sets of plots were located as close to each other as possible. In some fields the plots had to be located relatively far apart due to the mosaic pattern of past *Mucuna* use history. In two of the 38 fields in 1995, and one of the 26 fields in 1996, *Mucuna* and no-*Mucuna* plots were sited in different, but adjoining fields. Though in most cases plot location was constant in 1995 and 1996, in two fields plot location had to be changed at the beginning of the 1996 cropping season due to changes in the farmers' cultivation practices.

Monitoring Protocols

Periodic visits to the monitoring plots and one-time measurements constituted the core of the monitoring activities. The periodic visits were conducted at the following times: at maize planting, at 3 and 6 wk after planting (WAP), at 70% maize tasseling, and at doubling. To describe the *Mucuna* production component, the monitoring consisted of *Mucuna* biomass measurements, measurements of additional biomass variables, and measurements to describe *Mucuna* management. Data collected on environmental variables is described in the section on maize. The principle variable used to describe maize growth was maize grain yield. Data were also collected on maize biomass, chlorophyll content, and management. The environmental variables measured in each plot were: slope, soil chemical characteristics (pH, P, K), pest and disease incidence, and date to 70% tasseling. Rainfall was measured in each village. Additional, unscheduled visits were made to observe farmer management and crop growth, and to solicit management information from the farmers.[7]

Mucuna biomass measurement

Above-ground *Mucuna* biomass was measured in two quadrats per plot. In System A, biomass measurements were taken just prior to slashing (typically in

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[7] The line from observational to experimental was crossed with *Mucuna* planting by the researcher in 4 fields in 1995 and 2 fields in 1996. Owners of these fields told late in the season that they did not intend to plant *Mucuna*.

November) while in System B, biomass was measured at its estimated maximum typically in late December through early February.

Due to the uneven distribution of the *Mucuna* biomass in intercropped conditions (as described in Chapter 3), a fixed number of maize rows were included in the biomass measurement (two rows in 1995 or one in 1996). Quadrats were demarcated squares whose sides were the distance from the middle of one maize alley to the middle of the next. Two quadrats were sampled per *Mucuna* plot. The location of these sampling units was determined randomly in 1995. In 1996, quadrats were sited purposely in order to obtain representative samples in conditions where within-plot variability was considerable.

A rope placed between pegs demarcated the four sides of the quadrat. *Mucuna* was cut at ground level with a machete and the foliage was hand separated on site into *Mucuna* leaf, stem, and pods (1995) and *Mucuna* leaf, stem, pods, and mulch (1996). Pod fraction included both immature pods and mature pods. Mulch fraction included all dead plant residues on soil surface, excluding wood. In both years, live weeds were separated and measured. The fresh weight of the biomass fractions was measured in the field using hanging balances. Plot-level samples (typically 300-500 g) of each fraction were oven-dried and measured for dry weight (in 1995) or measured for dry weight and taken for further nutrient analysis (in 1996).

In 1995, *Mucuna* senescence was early in some villages, seemingly due to weather conditions, and biomass measurements in some fields were consequently conducted after maximum biomass. In such fields, *Mucuna* was further fractionated into dried leaves and dried stems.

Additional biomass measurements

Additional measurements of *Mucuna* biomass were conducted prior to summer maize planting to collect data on the quality and quantity of *Mucuna* mulch. In Santa Rosa and La Candelaria, separate samples of leaf, pod, and stem fractions of *Mucuna* were taken just prior to slashing in May 1997. Samples were collected from at least six locations per plot where these fractions were visible. A subsample (300-500 g) was oven dried and analyzed for N and P concentration. In the same two villages in June 1997, just prior to summer maize planting, fresh mulch biomass was measured in *Mucuna* and no-*Mucuna* plots. Measurements were taken from two representative (purposely selected) quadrats of 0.5 m x 0.5 m within each plot. The average of the two was taken as the mulch biomass for the plot. A subsample (300-500 g) was oven dried, after which dry weight was taken and the sample was analyzed for N and P.

Mucuna management variables

The following data were collected on the management of *Mucuna*:

- Choice of maize-*Mucuna* system. The farmer's choice of maize-*Mucuna* system (either A or B) was characterized in discussions with the farmer and confirmed in field observations.
- Planting date. In periodic farmer and field visits, plans for and progress of *Mucuna* planting were assessed.
- Self-seeding vigor and density. In Santa Rosa and La Candelaria in 1996 and 1997, *Mucuna* plots where maize-*Mucuna* System B had been utilized were visited prior to summer maize planting to collect information on *Mucuna* seed

density. *Mucuna* seeds in ten quadrats (0.5 m x 0.5 m) in the *Mucuna* plots were counted; the average count was taken as the average *Mucuna* seed density for the plot. In 1996 only, the number of self-seeded *Mucuna* plants was counted at planting, 3 and 6 WAP, and at flowering.

- Planting density. At maize flowering, the number of planted *Mucuna* seedlings was counted if *Mucuna* had been planted already; otherwise a separate visit was made. Planted *Mucuna* could be distinguished from the self-seeded *Mucuna* by its regular distribution and even development.
- Burning. The presence or absence of burning prior to summer maize planting was determined during field visits and farmer discussions.
- Prior *Mucuna* use. The duration of prior *Mucuna* use in the monitoring plots was noted during initial discussions with farmers.
- Weediness. The weediness of plots was assessed (scoring of 0 to 6) during maize flowering, which typically coincided with *Mucuna* seedling stage.

Maize yield measurements

Summer maize yield was measured in November 1995 and December 1996. The purpose of the yield measurements was both to assess total yield and yield components, as well as to estimate the impact of pests and disease on maize yield.

All harvest measurements were made in the field. Each of the four plots in all monitoring fields was harvested in full. After harvesting and husking, the cobs were divided into four groups: large healthy, small healthy, partially damaged, and completely damaged. The number of cobs and their weight was determined for each group. From the first three groups, 20 randomly chosen cobs were weighed. After shelling, grain weight was taken and grain moisture was determined with a portable Dickey John HM Grain Moisture tester. For the partially damaged cobs, the farmers doing the shelling were asked to shell the cobs as they would for home consumption, and the shelled grain was then weighed. Grain yield at 15% moisture was calculated for the three groups from the shelling percentages. Late-season monitoring visits and harvest measurements together allowed for the following maize yield components to be measured: number of plants, number of cobs, cobs per plant, and cob weight.

Maize chlorophyll measurement

Chlorophyll readings have been found to correlate with leaf N concentration in maize (Wood et al., 1992; McCullough et al., 1994). Chlorophyll readings were taken for the fifth leaf from the top of all plants in approximately 10 equidistant hills per plot. Each reading was taken at mid-leaf with a hand-held chlorophyll meter. Such a reading is based on the amount of light transmitted and corresponds with the chlorophyll content of the leaf. The average amount of chlorophyll was calculated per plot.

Maize management variables

Data on the following maize management variables were collected:

- Maize variety. The great majority of farmers plant traditional varieties which are typically characterized only as *criollo*. A few farmers in both years planted improved varieties that had been utilized for varying numbers of years.

- Planting date. In periodic farmer and field visits, plans for and progress of maize planting were assessed. In the analysis, planting date was recorded as a day from the first planting.
- Plant density. In 1995, initial planting density was assessed at 6 WAP by counting the number of all hills and multiplying it by the average number of plants per hill in approximately 20 equidistant hills. In 1996, plant density was assessed by counting the total number of plants in all plots at 3 WAP. In 1995, changes in plant density through the growing season were assessed in three rows per plot, where plant density was counted at 3 and 6 WAP and at flowering. In a subset of plots in 1995 only, plant density at harvest was measured by counting all plants in the plot.
- Weed management. The management of weeds was assessed utilizing three methods. First, a qualitative evaluation of weediness (score from 0 to 6) was undertaken at planting, 3 and 6 WAP, and at flowering. Second, in 1996 only, weed biomass at 4 WAP was measured from two 1-m by 1-m quadrats. The fresh weight was taken in the field, and a subsample was oven dried for dry weight analysis. Finally, in both years during periodic visits and farmer interviews, the number of weedings per plot was recorded. The data analysis focuses on the two indicators of the weed management that were judged most accurate: average weediness at early season (planting-3 WAP) and late season (in 1995: 6 WAP-flowering; in 1996: flowering). Weed biomass at 4 WAP was not judged to be of consistent value because it greatly depended of the timing of the weeding. Due to variability in the thoroughness of farmers'

weeding, number and timing of weedings described weed pressure less accurately than average weediness. Of note: *Mucuna* volunteers in plots were not considered in the weediness evaluation. They were, however, counted during periodic monitoring visits in 1996.

- Burning. The presence or absence of burning prior to summer maize planting was determined during field visits and farmer discussions.
- Input use. The great majority of farmers utilized herbicides but did not utilize any fertilizer. The amount and timing of fertilizer use was determined in farmer discussions.

Environmental variables

- Soil chemical characteristics. Soil was sampled from eight equidistant sites per plot, taken at maize planting time at depths of 0 to 5 cm and 5 to 20 cm; such samples were then composited within a plot and depth for laboratory analysis.
- Slope. For each plot, slope was evaluated both qualitatively (slope, no slope) and measured as percentage on plot level.
- Pest and disease. The incidence of pest and disease in maize was recorded at intervals of 3 and 6 WAP and at flowering by counting the number of plants with visible symptoms per plot. At harvest, number of ears with no economic yield and number of partially damaged ears per plot were recorded.
- Date to 70% tasseling. This date was identified by frequent visits to the plots at times approaching flowering.

- Rainfall. Rainfall data were collected on a village basis throughout the 2 yr of monitoring. Two farmers per village made independent measurements with standard gauges sited close to their homes.

Laboratory Analyses

Mucuna biomass samples were ground in a Wiley mill to pass a 1-mm stainless steel screen and then were analyzed for N and P concentration. For N, a modification of the aluminum block digestion technique was used (Gallaher et al., 1975). In the digestate, ammonia was determined by semi-automated calorimetry (Hambleton, 1977). Nitrogen concentration is reported on an OM basis.

Soil samples were analyzed for P and K utilizing the Mehlich I procedure. For organic matter, a modified Walkley-Black procedure was utilized (Hanlon et al., 1994). Average P, K, and pH values for the study villages is presented in Table 4-2.

Data Analysis

Data were subjected to analysis of variance utilizing both PROC GLM and PROC MIXED procedures (SAS Institute, Inc., 1989) after appropriate log and arcsine transformations were done. *Mucuna* biomass and management as well as maize yield, yield components, and maize management were analyzed by PROC GLM. For *Mucuna* biomass, the model contained the following terms: village, field (village), treatment. Treatment and village were tested against field (village), and sums of squares I was used. For maize yield data a model was used that contained the following terms: village, field (village), treatment, village by treatment, field by treatment (village), and replication (village by field). Field (village), field by treatment (village) and replication (village by field) were specified as random, and test option was used for correct error terms. PROC MIXED was utilized to compare least square means of maize yield and *Mucuna* biomass fractions among groups of fields (using the p-difference option); least square means were produced by utilizing the above-mentioned model. Such groupings were made either by directly comparing discrete variables in management (e.g., burn vs. no burn) and environment (e.g., slope vs. no slope), or by dividing continuous variables (e.g., plant density) into three groups (low, medium, high). These groups were defined as approximate one-thirds. Plotting, correlations, and regressions were also utilized for the analysis of management and environment variables. For descriptive purposes, PROC UNIVARIATE was utilized.

Results and Discussion

Mucuna Growth in 1995 and 1996

In both years, the average live *Mucuna* biomass without mulch remained less than 2 t ha^{-1}; in 1996, the average biomass was 4.3 t ha^{-1} with mulch (Table 4-3). *Mucuna* biomass was highly variable, and remained very low in a large number of plots. In a full 50% of plots, *Mucuna* live fraction remained at or below 1680 kg ha^{-1} in 1995, while in the lowest 25% of plots, biomass was below 650 kg ha^{-1}. In 1996, the *Mucuna* biomass (including mulch) was less than 3530 in 50% of the plots, while the *Mucuna* live fraction (including pods) was below 1700 kg ha^{-1} in 50% of plots.

These results are considerably less than biomass obtained in sole-cropped summer conditions in the experiments (averaging 7.6 t ha^{-1} including mulch, see Chapters 6 and

7). Due to losses through volatilization and leaching, 2 t ha^{-1} has been suggested as the minimum biomass for significant N contribution to take place (Lobo Burle et al., 1992).

Table 4-2. Means and standard deviations (in parentheses) of soil pH, K, and P at two depths in different villages. Soil P and K were determined using the Mehlich I extractant.

	La Candelaria		Santa Rosa		San Fernando		Sotea-pan	Salto de E.
Variable & depth	1995	1996	1995	1996	1995	1996	1995	1996
pH, 0-5 cm	6.2 (0.3)	6.3 (0.5)	6.1 (0.2)	6.1 (0.3)	6.1 (0.3)	6.2 (0.2)	6.2 (0.3)	7.8 (0.4)
K, 0-5 cm (mg kg^{-1})	168 (81)	154 (74)	164 (104)	138 (85)	206 (131)	242 (119)	229 (120)	67 (32)
P, 0-5 cm (mg kg^{-1})	2.92 (0.63)	4.27 (4.14)	3.94 (3.62)	4.23 (4.27)	4.06 (2.73)	4.67 (3.09)	8.02 (10.31)	8.31 (7.36)
pH, 5-20 cm	6.2 (0.2)	6.4 (0.5)	6.0 (0.2)	6.0 (0.2)	6.0 (0.3)	6.1 (0.3)	6.0 (0.3)	7.8 (0.3)
K, 5-20 cm (mg kg^{-1})	85 (56)	80 (52)	88 (56)	77 (48)	122 (67)	128 (60)	118 (64)	55 (25)
P, 5-20 cm (mg kg^{-1})	2.84 (1.97)	3.25 (2.13)	2.63 (1.56)	2.70 (1.77)	2.67 (1.20)	3.06 (1.68)	5.56 (7.77)	5.40 (6.54)

Although *Mucuna* biomass was similar between year, 1996 average weed biomass was only half that of the previous year. This was to a large extent caused by a larger share of plots with System A (which typically have lower weediness), and by the inclusion of Salto de Eyipantla in 1996, where weediness tended to be low. In addition, weed biomass in 1995 may have been unusually high, as *Mucuna* senescence started unusually early, opening up unshaded areas in which weeds could grow.

Table 4-3. Average and standard deviation (in parentheses) across fields of *Mucuna* biomass fractions in 1995 and 1996.

Fraction	1995	1996
	----------------- kg ha^{-1} -----------------	
Leaf+stem	1 260 (840)	1 130 (740)
Pods	600 (710)	720 (690)
Mulch	†	2 420 (1 760)
Weed	1 330 (1 150)	760 (650)

† Not measured; partly included in leaf and stem component.

As discussed above, the combined *Mucuna* leaf and stem biomass fractions, which averaged over 1 t ha^{-1} both years, contained a part of the mulch fraction in 1995 and therefore cannot be directly compared between the years. The "true" combined leaf-stem biomass in 1995 presumably would have been lower than that of 1996. Pod fraction in 1996 was slightly higher, despite the larger share of plots in System A (with typically lower pod biomass). This was mostly caused by the inclusion of Salto de E. in the study, with the relatively higher production, later winter maize planting dates, and more advanced *Mucuna* maturity. It was also caused in part by a larger number self-reseeded *Mucuna* in the fields which had already advanced to pod-production stage at the time of slashing in System A.

In summary, in these diverse environments, farmer-managed, intercropped *Mucuna* produced highly variable, but generally relatively low biomass. In a large number of plots the *Mucuna* biomass was clearly inadequate for strong short-term benefits to maize yield or soil conservation. In contrast, on-farm and experimental results obtained elsewhere in the tropics show greater *Mucuna* biomass, though results are often hard to compare due to inadequate description of methods. In the farmer-managed fields of Triomphe's Atlantic Honduras study, average biomass measured in 101 fields in 1993 were far greater, at 11.4 t ha^{-1} (Triomphe, 1996; Buckles et al., 1998). What is striking, however, is the much lower variability in such biomass, with a standard deviation of only 1.9, or almost only one-sixth of the average. In contrast, standard deviations of the total *Mucuna* fraction in 1995 (leaf, stem and pod) and 1996 (leaf, stem, pod and mulch) was 75 and 62% respectively. In discussing Triomphe's study, Buckles et al. (1998) hypothesize that the large mulch layer and long growing period there account for the stability of *Mucuna* biomass; in contrast, the growing period is shorter, and the mulch layer more limited in Veracruz.

In experimental conditions, *Mucuna* biomass production has varied greatly. Sanginga et al. (1996a), reporting on the transitional zone between savannah and humid forest, obtained *Mucuna* biomass of 7.7 t ha^{-1} in uninoculated, sole-cropped conditions in 12 wk; such biomass was reduced by 25% if *Mucuna* was intercropped with maize. Gilbert (n.d.), planting *Mucuna* in Malawi, obtained a biomass of 3 t ha^{-1} when *Mucuna* was planted 2 wk after maize, but serious competition with maize resulted.

Mucuna Management and its Effects on *Mucuna* Biomass

The impact of management factors on *Mucuna* biomass production was quantified more successfully than that of environmental factors. Due to space constraints, the following discussion focuses mainly on the impact of management on one of the combined *Mucuna* biomass fraction, the live fraction (consisting of leaf, stem, and pods).

1. Choice of maize-*Mucuna* system

There was a clear impact of the choice of maize-*Mucuna* system on biomass production both in 1995 (p=0.003) and 1996 (p=0.041; Table 4-4). Pod and total *Mucuna* production each year were higher in System B, where *Mucuna* matures in the field. In 1995, combined leaf and stem production was higher in System B (p=0.024), but in 1996 no such effect was seen, presumably due to the inclusion of Salto de E., where *Mucuna* productivity was greater and System A predominated. Mulch fraction, measured only in 1996, averaged about 1 t ha^{-1} more in System B (p=0.002). Seemingly only a part of this mulch fraction increase is of *Mucuna* origin. Weed biomass in both years tended to be higher in System B, both in absolute terms (three to four times higher) and as a share of total biomass. This high weediness in System B seemingly reflects the relatively slow development of *Mucuna* (as discussed in Chapters 5 and 6, *Mucuna* outcompeted weeds more effectively in System C).

In 1995, System A had a larger number of plots with very low biomass (Table 4-5). That year, 50% of the plots had combined leaf-stem biomass of 830 and 1230 kg ha^{-1} or less for Systems A and B, respectively. This was not the case in 1996 due to the presence of Salto de E.

Several factors in the study design made it problematic to discern the effect of system on the *Mucuna* biomass. First, the number of observations per system is quite limited. Second, within the two systems the management practices were highly variable, in particular, planting density and number of self-seeded plants varied greatly between fields. This, coupled with high variability in environmental factors makes it difficult to detect the impacts of such factors or the choice of system on the biomass production. Thirdly, as the two *Mucuna* monitoring plots within a given field typically represented only one system, the system effect is confounded with the field effect. Fourthly, use of the two maize-*Mucuna* systems varied by village, either due to farmers' choice, or due to differences in growing conditions. Specifically, local conditions in San Fernando allowed only one maize cycle, thus restricting farmers to System B, while in Salto de E. two maize cycles were always grown and therefore farmers favored System A. This further complicated the analysis, as the system effect at times was confounded with the village effect--a topic we explore further in a later section.

Table 4-4. Weight of *Mucuna* biomass fractions as affected by maize-*Mucuna* systems in 1995 and 1996.

Biomass fraction	1995			1996		
	System A†	System B‡	p-value	System A†	System B‡	p-value
	------ kg ha^{-1} ------			------ kg ha^{-1} ------		
Leaf+stem	950	1 320	0.024	1 430	1 010	0.270
Pod	0	740	<0.001	450	890	0.004
Weed	380	1 580	0.114	330	940	0.407
Mulch	§	§	§	1 800	2 720	0.002
Mucuna total¶	950	2 060	0.003	3 680	4 620	0.004

† At slashing of summer-intercropped *Mucuna*.

‡ At maturity of summer-intercropped *Mucuna*.

§ Mulch not measured in 1995.

¶ In 1995, includes leaf+stem+pod fractions; in 1996, includes leaf+stem+pod+mulch fractions.

Table 4-5. Percentiles of *Mucuna* leaf+stem biomass in systems A and B in 1995 and 1996.

	1995		1996	
Percentile†	System A‡	System B§	System A‡	System B§
	--------- kg ha^{-1} ---------		--------- kg ha^{-1} ---------	
100	2 070	4 010	4 580	4 030
75	1 470	1 860	3 370	2 610
50	830	1 230	1 860	1 700
25	370	610	1 300	1 380
0	180	140	10	260

† Percentage of plots with lower biomass.
‡ At slashing of summer-intercropped *Mucuna*.
§ At maturity of summer-intercropped *Mucuna*.

2. Planting date

As described in Chapter 3, *Mucuna* planting typically took place later than recommended by extension workers and the literature. On average, *Mucuna* planting took place at 60 to 70 DAP maize, not at 30 to 50 d as had been reported (Table 4-6). Interviews and discussions with farmers revealed that later planting was partially caused by farmers' attempt to avoid smothering of maize by *Mucuna*. As discussed in Chapter 2, competition usually does not take place if *Mucuna* is planted starting 40 DAP maize. Fears of competitive effects may therefore not fully explain such late planting dates. Competition for labor may explain some late planting dates. Some weeding of maize may still take place in August, while coffee is also weeded in August. Moreover, farmers who planted *Mucuna* later typically also seemed less interested in *Mucuna*, or less convinced of its benefits, thereby not considering its planting a priority.[8] Supporting this observation is the fact that farmers who planted *Mucuna* over 90 DAP maize in 1995 did not plant *Mucuna* at all in 1996; these farmers either discontinued *Mucuna* use or relied on *Mucuna* self-seeding. This factor largely explains the earlier average planting time for 1996.

Table 4-6. Average and standard deviation (in parentheses) across fields of *Mucuna* management practices in 1995 and 1996.

Management practice	1995	1996
Planting date†	67 (23)	59 (16)
Planting density ha^{-1}	16 810 (11 600)	10 100 (7 200)
Self-reseeding density ha^{-1}	1 500 (3 650)	3 700 (5 600)
Total plant density ha^{-1}	18 240 (11 500)	13 800 (6 860)

† As days after maize planting.

The comparison of biomass among groupings of low, medium, and high levels of a particular management factor lend support to the importance of *Mucuna* planting date (Table 4-7). In 1995, plots planted before 50 DAP maize tended to have higher biomass (p=0.138) than those planted 50 to 70 DAP maize. The latest-planted plots did not differ significantly from the other two, but half of them were located in San Fernando, where rains (and *Mucuna* growth) continue into the winter period, and late planting time consequently matters less. In 1996, the yield least square means of the earliest planted plots were about 1 t ha^{-1} greater than the latest-planted group (p=0.007).

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[8] The late planting by two farmers in 1995 was caused by misinformation on the PROCAMPO subsidy program (i.e., no maize subsidies if *Mucuna* was intercropped).

Table 4-7. Least square mean of *Mucuna* live fraction (leaf, stem, pod) biomass as affected by management in 1995 and 1996.

		Grouping of fields by level of management variables			P-value		
Variable	Year	Low†	Med.	High	L vs. M	L vs. H	M vs. H
		----- kg ha^{-1} -----					
Planting date	1995	1 480	870	1 190	0.138	0.674	0.379
	1996	2 260	1 910	1 260	0.731	0.007	0.015
Total plants ha^{-1}	1995	700	1 460	1 260	0.172	0.127	0.578
	1996	2 000	1 450	2 330	0.071	0.616	0.057
Self-reseeding (%)	1995	1 150	1 420	1 640	0.614	0.511	0.824
	1996	1 330	1 980	2 200	0.287	0.038	0.279

† Low includes the fields with the earliest planting dates.

3. Planting density and self-seeding

A third management factor affecting *Mucuna* biomass is *Mucuna* planting density. Average *Mucuna* planting densities were approximately 17 000 and 10 000 for the two study years, respectively (Table 4-6). On average, a higher proportion of *Mucuna* density was self-seeded in 1996, which was at least partly associated with the smaller number of first-year *Mucuna* fields. Such densities are lower than the recommended 20 000 plants ha^{-1}. In both years, some fields were planted at a higher density but germination was poor, presumably due to low seed quality.[9] In other fields, planting density was poor either due to large spacing and/or planting of only one seed per hill. The owners of such fields often referred to insufficiency of seed as the cause for low planting densities.

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[9] Low seed quality seemed often associated with poor handling and storage.

Impacts of planting density were not very clear. Groups with lowest and highest planting densities did not differ (p=0.127 and 0.616 for 1995 and 1996, respectively) in live fraction yield and there were only trends to support the importance of plant density (Table 4-7). One should note that the densities involved were generally relatively low. In both years, *Mucuna* live fraction tended to be higher in plots with higher percentage of self-seeded plants; in 1996, yield least square means of plots with highest percentage of self-seeded plants was about 900 kg ha^{-1} more. These self-reseeded plants typically had already established themselves by the *Mucuna* planting time, and therefore had a longer growing period.

In 1996, a larger number of germinated plants were self-reseeded, which was caused in part by fewer first-year *Mucuna* fields. Total plant densities were also lower, which is partially explained by the absence of Soteapan, where the densities in 1995 were clearly higher. In Santa Rosa and La Candelaria, though planting densities were lower in 1996, total densities were only slightly lower due to the increased self-reseeding.

Though there are little data on *Mucuna* planting densities and dates utilized by farmers, Triomphe (1996) reported that in the initial establishment of *Mucuna* in Atlantic Honduras, *Mucuna* is intercropped in maize 40 to 60 DAP maize, two to three seeds per hole which are 1 to 2 m apart. Such practice therefore resembles that of the farmers in Veracruz. Subsequent establishment, however, takes place mainly through self-seeding. As reviewed in Chapter 2, in many of the experimental situations, planting densities utilized for *Mucuna* have typically been higher, from 55 000 plants ha^{-1} (Yost et al., 1985) to 148 000 plants ha^{-1} (Soil Fertility Network, n.d.). As discussed earlier, Buckles et al. (1998) hypothesize that in Triomphe's (1996) study in the Atlantic Honduras, the stability of the *Mucuna* biomass production is caused by the large quantities of semipermanent mulch and the long growing period for *Mucuna* (at least 8 mo), which compensates for management variability. By contrast, it could be further hypothesized that the relatively shorter growing period for *Mucuna* in the farmer-practiced systems in Veracruz may cause greater reliance of biomass production on such management factors as planting density. As discussed in Chapter 2, the impacts of density on the rapidity of *Mucuna* establishment, and on the final biomass have largely been ignored by investigators; it is consequently difficult to hypothesize regarding what may be the effect of generally higher planting densities on *Mucuna* biomass.

4. Burning practice

In 1995, 65% of the plots had been burnt prior to summer maize planting. All but one of the non-burnt fields were in La Candelaria. In 1996, only 35% of the total fields were burnt, but all farmers in San Fernando continued burning.[10] We might expect that burning would impact *Mucuna* biomass in two ways: by decreasing the mulch fraction, and by decreasing the percentage of viable seed that reseeds. However, there was no difference in the next season's *Mucuna* live fraction between previously burnt plots and plots that had not been burnt in 1995 ($p=0.422$). In 1996, *Mucuna* live fraction tended to be higher in plots which had not been burnt (1560 kg ha^{-1}) than in the plots that had been burnt (1070 kg ha^{-1}; $p=0.115$). The absence of a strong impact of burning is presumably caused by three factors. First, the practice of burning varied greatly, from a full burn to a technique where the farmer collects litter in piles that are burnt. Second, the mulch biomass of a particular year is most strongly influenced by the *Mucuna* and weed growth that particular year. Finally, the practice of not burning crop residues is new, and the mulch layer is of limited size. Presumably in the future the difference in mulch content between burnt and non-burnt fields will become larger.

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[10] The 1996 figure does not include Salto de E., where plowing is common.

5. Duration of prior *Mucuna* use

In 1995, no differences in *Mucuna* biomass were found between the plots being used to grow *Mucuna* for the first, second, or third year (Table 4-8). Biomass tended to be highest in the first-year plots. In 1996, biomass in the third-year plots was lower than for the other years. Such an effect is presumably caused mainly by the field effect, and is therefore difficult to interpret. This study, however, does not support the frequently mentioned argument that *Mucuna*'s growth may be poor in the first year in some fields, but in subsequent years its growth improves, presumably due to increase in appropriate rhizobia. In fact, first-year *Mucuna* seemingly nodulated quite well, as does the common bean in the area (Vincent Vadez, personal communication). This finding is not conclusive, however, as the detection of such effects might have required a larger number of fields, given the great variability among fields.

The non-independence of management factors impacting *Mucuna* biomass.

In interpreting the impact of management on *Mucuna* biomass, a word of caution is in order. The management factors did not always act independently, but at times were significantly correlated. The strength of such correlations were typically from weak to moderate. For example, in 1996, the plots in which *Mucuna* was planted late also had a higher number of self-seeded *Mucuna* (r=0.441, p=0.006). Such plots were also planted more sparsely (r=-0.509, p=0.001) and their total density was less (r=-0.462, p=0.004). In 1995, fewer such trends existed. Plots planted later with *Mucuna* were actually associated with a lower number of self-seeded *Mucuna* (r=-0.323, p=0.011), and no association existed between late planting dates and planting densities. In both years, however, planting densities were lower in plots where there were more self-seeded plants (1995: r=-0.383, p=0.002; 1996: r=-0.553, p<0.001).

Table 4-8. Least square means of *Mucuna* live fraction (kg ha^{-1}) as affected by the length of *Mucuna* use.

	Years of Mucuna use			
Year	1	2	3	4
	- - - - - - - - - kg ha^{-1} - - - - - - - - -			
1995	1 470a†	1 090a	1 270a	‡
1996	2 400a	2 220a	1 170b	2 250a

† Means within a year followed by the same letter are not different by p-difference (p>0.10).
‡ No fourth-year fields included.

Not surprisingly, there was a positive association between year of *Mucuna* use and number of self-seeded plants (1995: r=0.435, p<0.001). In 1996, two fields which had not been burnt after the previous year's *Mucuna* crop had very high densities of self-seeded *Mucuna*. The non-independence of management factors could cause an overestimation of some factors' importance. Field observations, however, lend support to the importance of *Mucuna* density and planting date as factors significantly impacting biomass.

Though this study did not focus on elucidating the farmers' rationale for their management practices, the above-cited associations among management variables do help us in identifying the rationale behind certain management strategies. First, farmer management of *Mucuna* in many fields is flexible in that density obtained through self-seeding is seemingly supplemented by planting. Second, in some fields *Mucuna* management appeared to be quite casual, as suggested by associations between late planting time and low density. Field observations again lend support to these inferences.

Environmental Factors and Their Effects on *Mucuna* Biomass

This study could only poorly quantify impact of environmental factors on *Mucuna* biomass production.

1. Soil characteristics

As with maize yield, correlations of biomass fractions with soil P, K, and pH were non-existent, inconsistent, or low. However, field observations clearly affirmed that *Mucuna* growth was favored by higher-fertility soil. Typically, growth was more rapid and runners longer and thicker, in the higher-fertility fields. Tian et al. (1997), in analyzing *Mucuna* growth in degraded and higher-fertility soil, affirmed the importance of soil fertility in explaining *Mucuna* biomass; such research was further reviewed in Chapter 2.

2. Slope

Though field observations suggested that growth in fields with steeper slope in many cases tended to be poorer than in flat ones, such differences could not be clearly confirmed due to the relatively small number of plots located in flat areas, and the confounding of slope with village in 1996.

In 1995, there were only 10 observations for live fraction biomass in flat plots (and 52 for sloping plots); their mean was slightly lower (1660 vs. 1890 kg ha^{-1}) than in plots with slope. In 1996, 28% of plots were located in flat areas, but about 60% of them were in Salto de E. The plots with slope tended to have a lower live fraction (least square mean 1690 vs. 2310 kg ha^{-1}) but such difference was not significant (p=0.495).

3. Pest and disease damage

Little pest and disease damage was observed in these farmer-managed *Mucuna* plots. No quantification of such damage took place.

Explaining *Mucuna* Biomass Variability on Village, Field, and System Levels

The variability in *Mucuna* biomass was examined through ANOVA in an effort to determine whether these plot-level data could be meaningfully intepreted at the levels of system, field, and village (Table 4-9). There were field (p<0.001) and system (p=0.041) differences both in 1995 and 1996. Due to the large variability at the field level, no significant village effects were discovered despite the fact that *Mucuna* performance seemingly did differ at the village level. In the following, the impacts of village and field will be discussed, the effect of system having been explored above under management variables.

Village-level effect on *Mucuna* biomass

From field observations it was anticipated that, management differences aside, *Mucuna* growth would be found to vary among the five study villages. Growth appeared to be favored by the environmental conditions in San Fernando and especially in Salto de E. Though San Fernando's winter weather is cooler, *Mucuna* growth was presumably favored by its more evenly distributed rainfall and higher soil fertility. In Salto de E., *Mucuna* clearly thrived in the moister and more fertile soils. Indeed, initial reconnoisance visits suggested that village-level effects on *Mucuna* biomass would prove to be both (1) large, and (2) primarily environmental in origin.

Table 4-9. Analysis of variance of *Mucuna* live fraction biomass.

Effect	1995 p-value	1996 p-value
Village	0.517	0.729
Field (village)	<0.001	<0.001
System	0.003	0.041

Interestingly, the monitoring data did not bear out these initial suppositions. Large environmental and management variability among fields within a village both in 1995 and 1996 made it difficult to detect differences in *Mucuna* biomass among villages. As is clear in Table 4-10, trends only, but not clear differences, were evident among villages. Moreover, these trends were presumably attributable to *Mucuna* management variables as much as environmental ones.

Both *Mucuna* planting dates and densities differed by village (Tables 4-10 and 4-11). In Soteapan in 1995, planting took place early, and planting densities tended to be quite high. In San Fernando, planting took place unusually late. Slower maize development due to environmental conditions partially caused such late planting; another factor was the seemingly low interest in *Mucuna* in this village, as mentioned previously. In Santa Rosa and La Candelaria, distribution of density and planting dates was roughly similar both in 1995 and 1996. In 1996, planting dates and densities in Salto de E. were strikingly uniform; planting took place relatively early and relatively close to the recommended density. The farmers planting *Mucuna* in Salto de E. were relatives of the farmer extentionist; presumably this explains the adherance to his recommendations.

Table 4-10. Percentiles of *Mucuna* planting date (days after planting maize) and total plant density in the four study villages in 1995.

Percentile†	Planting date				Total density ha^{-1}			
	La Cand.	S. Rosa	Sot.	S. Fern.	La Cand.	S. Rosa	Sot.	S. Fern.
100	86	110	71	122	22 600	41 500	53 200	32 700
75	73	69	61	116	17 800	19 500	33 700	28 800
50	54	58	56	92	14 100	14 550	22 500	12 850
25	45	52	49	80	9 750	7 400	16 500	8 000
0	40	44	42	51	1 200	2 200	10 600	6 500
V mean	59	67	55	92	13 250	15 030	26 390	18 140
(SD)	(17)	(24)	(8)	(25)	(5 880)	(9 980)	(14 010)	(10 380)

† Percentage of plots with earlier planting dates or lower plant densities.

Table 4-11. Percentiles of *Mucuna* planting date (days after planting maize) and total plant density in the four study villages in 1996.

Percentile†	Planting date			Total density ha^{-1}		
	La Cand.	S. Rosa	Salto	La Cand.	S. Rosa	Salto
100	86	110	71	22 600	32 100	27 500
75	73	69	61	15 400	17 500	17 000
50	54	58	56	11 900	12 550	14 300
25	45	52	49	8 700	10 300	11 200
0	40	44	42	3 200	4 600	10 400
V mean	61	57	50	12 920	13 970	15 480
(SD)	(19)	(16)	(5)	(5 510)	(7 080)	(5 460)

† Percentage of plots with earlier planting dates or lower plant densities.

Such management differences seem clearly to have impacted biomass at the village level (Table 4-12). In 1995, Soteapan contained the largest number of high-yielding plots. Especially San Fernando, but also Santa Rosa had a disproportionate share of low-yielding *Mucuna* plots. Often, such low-yielding plots seemingly resulted from casual management in these villages. In 1996, little difference in the distribution of the live fraction existed between Santa Rosa and La Candelaria, while Salto de E. clearly had more higher-yielding *Mucuna* plots.

Table 4-12. Percentiles of *Mucuna* live fraction biomass in the study villages in 1995 and 1996.

	1995				1996‡		
Percentile †	La Candelaria	Santa Rosa	Soteapan	San Fernando	La Candelaria	Santa Rosa	Salto de E.
	kg ha^{-1}						
100	3 380	3 350	6 760	3 560	4 030	3 360	4 580
75	2 660	2 320	3 760	2 710	2 090	2 650	3 520
50	2 230	1 630	1 930	730	1 610	1 520	2 470
25	1 300	670	940	480	1 380	740	1 630
0	180	170	300	140	10	260	110
V mean (SD)	1930 (1080)	1610 (1020)	2430 (1980)	1470 (1250)	1690 (940)	1640 (940)	2560 (1340)

† Percentage of plots with lower *Mucuna* live fraction weight.

‡ For 1996, San Fernando is not included due to small number of observations

Field-level effects on *Mucuna* biomass

As later with maize yield, this study could only describe the large field-level variability in *Mucuna* biomass. Analysis of such variability is difficult. Due to the relatively small number of fields included in the study, and the fact that it was not possible to select fields, it is difficult to characterize the fields narrowly as the fields varied both in management (including the system) and in environmental factors. The separate impacts of such factors have already been discussed.

Maize Yield in 1995 and 1996

In the following, maize yield variability and yield components will be discussed, after which our attention will turn to the impact of management factors and environmental factors on maize yield. The impact of *Mucuna* will be addressed in Chapter 5.

Plot-level summer maize yield varied greatly both in 1995 and 1996. Plot-level yields were low both years, averaging 1090 and 1150 kg ha^{-1}, with large variability (standard deviations of 590 and 650 kg ha^{-1}, respectively). The lowest plot yield in both years was below 100 kg ha^{-1}, while yields of less than 500 kg ha^{-1} constituted 15 and 21% of the 1995 and 1996 yields, respectively. Yields exceeding 2000 kg ha^{-1} constituted only 8 and 9%, respectively. Close to half of the plot-level yields, 44 and 48%, were between 1000 and 2000 kg ha^{-1}.

Maize Yield Components

Of the maize yield components, the study quantified (1) plant density, (2) number of ears per plant, (3) ear density, and (4) ear grain weight.

Since plant density is both a yield component and a management factor (as planting density), it will be discussed under both of these sections. As a yield component, the focus is its association with yield (through correlation) and its relationship with the other yield components. As a management factor, its impact on maize yield is quantified through the comparison of yield least square means among plots where planting densities were low, medium, or high.

1. Plant density

Average maize plant density (measured at 6 and 3 WAP in 1995 and 1996 respectively) was approximately 32 500 and 33 000 plants ha^{-1} in 1995 and 1996. In 1995 and 1996, 25% of plots had plant densities that were 27 250 and 28 000 plants ha^{-1} or lower, respectively. In the upper 25th percentile, plant densities were 35 560 and 37 600 or greater in 1995 and 1996, respectively.

In 1995, these plant density estimations had a clear, but relatively low correlation with yield (Table 4-13). This overall trend varied greatly by village, as the number of plants had no correlation with yield in two villages, a moderate correlation in one, and a relatively strong correlation in another. In 1996, no overall correlation was found between number of plants and yield (p=0.693), but in Salto de E., where plant densities were highest, there was a moderate negative correlation (r=-0.465, p=0.081) between density and yield.

Table 4-13. Correlation of yield components (p-value in parentheses) with maize yield in 1995 and 1996.

Variable	1995	1996
Plant density ha^{-1}	0.374 (<0.001)	0.041 (0.693)
Ears ha^{-1}	0.896 (<0.001)	0.858 (<0.001)
Ears per plant	0.741 (<0.001)	0.813 (<0.001)
Ear weight (g)	0.718 (<0.001)	0.800 (<0.001)

The low predictive value of the plant density measurements was most likely related to two factors. Firstly, early counting of plant density underestimated the importance of plant density as a yield component. Secondly, the number of ears per plant varied greatly; this issue will be discussed in the following section.

The number of plants had been counted at 6 (1995) or 3 (1996) WAP. Row-level monitoring of approximately 250 rows in 1995 showed that on average, only about 4% of plants were lost between 3 wk and flowering. In the row-level data, plot-level correlation of yield to plant density at 3 WAP, 6 WAP, and at flowering increased only slightly with the advance of growing season, from 0.191 ($p=0.002$) at 3 WAP to 0.297 ($p<0.001$) at flowering. If plant counts conducted at harvest time in 1995 (only 36 plots) were utilized to calculate number of ears per plant, higher numbers were obtained (0.67 ears per plant present at harvest vs. 0.54 ears per plants present at 6 wk). It therefore seems that the early counting of plant density underestimates the importance of plant density as a yield component, but such influence is relatively minor.

Consequently, it appears clear that planting density is the single most important factor impacting maize plant densities at harvest in the area, as losses during the growing season seem relatively limited. The unimportance of plant losses is partly related to the prevalence of herbicide use. In contrast, in a study in a humid forest zone of Nigeria, maize plant losses were much greater, and attributable in part to damage during manual weeding (Eilitta, 1992). The impact on maize yield of plant losses between 3 WAP and flowering may be even less than suggested by the 4% decrease in plant number. Field observations suggest that a large share of the plants lost suffered from intra-hill competition, i.e., were the smallest plants in a hill that often would not have produced an ear anyway. Planting density itself therefore is the overriding factor impacting plant density at harvest.

2. Number of ears per plant

The relative unimportance of plant density as a component of yield seems to be caused by the great variability in the number of ears produced per plant. On the average, only 54 and 56% of plants present at 6 (1995) and 3 (1996) WAP, respectively, produced ears. Plots in the lower 25% of the yield range averaged less than 0.44 or 0.48 ears per plant in 1995 and 1996, while the upper 25% produced at least 0.66 or 0.68 ears per plant.

Number of ears per plant was clearly correlated with maize yield both in 1995 ($r = 0.741$, $p<0.001$) and 1996 ($r=0.813$, $p<0.001$; Table 4-13). Comparison of yield from plots with a low, medium, and high number of ears per plant also affirms ears per plant as an important factor explaining maize yield. Least square means of plots where less than 40% of plants produced ears was only about one half that of plots where more than 60% of plants produced ears (Table 4-14).

What explains the generally low number of ears per plant, and the relatively large variability associated with this component? Barrenness is typically associated with (1) environmental stresses during flowering, and (2) with excessive plant density (Fischer and Palmer, 1984; Bolaños & Edmeades, 1993; Buren et al., 1974). Maize is particularly sensitive to environmental stresses during flowering and grain production, as its flowering organs are both spatially and temporally separated (Bolaños and Edmeades, 1993). If after the initiation of flowering, the plant does not distribute enough dry matter to the developing ear, the probability of barrenness is quite high (Bolaños et al., 1990).

In the study villages, lower rainfall in August coincided with maize flowering in two of the study villages in 1995 and in one in 1996.

Table 4-14. Least square means of maize yield as affected by number of ears per plant in 1995 and 1996.

	Grouping of plots by level of ears per plant			p-value for contrasts		
Year	Low	Medium	High	L vs. M	L vs. H	M vs. H
	- - - - - - - - - kg ha-1 - - - - - - - - -					
1995	700	1 070	1 380	<0.001	<0.001	0.026
1996	690	1 130	1 490	<0.001	<0.001	0.023

In 1996, this study found a low negative correlation of plant density and number of ears per plant. Increased planting density has been associated with increase in variability of maize plant size and yield in a study by Edmeades and Daynard (1979) of maize hybrids grown at densities varying from 50 000 to 200 000 plants ha^{-1}. Bolaños and Barreto (1991), in analyzing a large number of experiments from Central America, concluded that sterility is common if biomass is less than 150 g per plant.

In Los Tuxtlas, despite low planting densities per hectare associated with the traditional planting practices, plant density per hill was high. Field observations suggest that typically, in a hill of three plants, only one or two ears were produced by the largest plants. The smallest plant in a hill often remained less than 1 m in height and barren; even the second largest plant could be barren. It seems clearly that barrenness is at least partly tied to intra-hill competition for both nutrients and water. In addition, smaller plants in the hills are shaded by the larger ones. Shading, which is also associated with increased plant density, has been associated with reduced maize yields especially if it occurs at flowering (Fischer and Palmer, 1984). The true impact of plant density in heterogeneous environments is, however, difficult to analyze, as its effect on maize grain yield is mediated by soil fertility (Carlone and Russell, 1987).

The association of number of ears per plant with other management factors and with factors describing maize growth (Table 4-15) remained weak overall. Weed pressure could be expected to increase competition for nutrients and water; indeed in both years, the association of ears per plant with weediness score was moderately negative. The association of the number of ears per plant with chlorophyll content implies better N status in plants with higher number of ears per plant. Finally, in 1996 a low negative correlation with plant density was found.

Table 4-15. Correlation of various management and environmental factors (p-value in parentheses) with ears plant^{-1}.

Variable	1995	1996
Plants ha^{-1}	-0.072 (0.416)	-0.269 (0.008)
Hills ha^{-1}	-0.039 (0.659)	-0.172 (0.096)
Date of planting	-0.037 (0.673)	0.188 (0.031)
Date of flowering	-0.093 (0.305)	0.028 (0.785)
Plants hill^{-1}	-0.041 (0.642)	n.s
Chlorophyll	0.303 (0.001)	0.340 (0.001)
Weediness	-0.407 (<0.001)	-0.365 (<0.001)

3. Ear density

In both years, total ear number per hectare was highly correlated with grain yield (Table 4-13). An average of 17 100 and 18 300 ears ha^{-1} were produced in the monitoring plots in 1995 and 1996, respectively. Plots in the lower quartile produced less than 12 950 (1995) and 15 200 ears ha^{-1} (1996), while those in the upper 25% produced more than 20 900 and 21 900 ears ha^{-1} in the two study years, respectively.

4. Ear grain weight

Ear grain weight was also strongly correlated with yield (Table 4-13). Average ear grain weight was low, at 67 and 66 g in 1995 and 1996, respectively. Plots in the lowest 25% had ear grain weights of less than 53 and 48 g in 1995 and 1996, respectively, while the highest 25% had ear grain weights greater than 80 and 77 g in the two study years, respectively.

Such low grain weights per ear are typically associated with problems during fertilization or grain-filling period. Drought stress at flowering tends to increase the interval between anthesis and silking, resulting in reduced number of grain per plant (Edmeades et al., 1993). Ear grain weight is also strongly influenced by N supply (Lemcoff and Loomis, 1986). In this study, lower weights are also associated with pest and disease incidence, as only economically usable grain was shelled. A high percentage, 45 and 60% of the ears with economic value, were partially damaged by pests or disease in 1995 and 1996, respectively.

Comparison to maize yield component relationships in other studies

These yield-component relationships for Los Tuxtlas resemble those of many other tropical investigations, whether experimental or monitoring. Most of such studies have been conducted in environments where maize yields are higher than those in this study.

In these studies, maize yield in low-yielding locations (often defined as yields less than 2.0-2.5 t ha^{-1}) has been associated with low number of plants, low number of ears per plant, and low ear weight (Beauval, 1988, cited in Bolaños et al., 1993). In several similar studies, plant density has had a relatively weak association with yield, for example, in Pierre (1992; cited in Bolaños et al., 1993), who studied yield formation in 23 farmers' fields in the Dominican Republic, and Bolaños and Barreto (1991), who reviewed 34 experiments in Central America. Rather than plant density, yield has been more strongly associated with the number of ears (Bolaños and Barreto, 1991; Bolaños et al., 1993) and with ear weight (Bolaños et al., 1993; Bolaños and Barreto, 1991). However, Turrent (1983; cited in Bolaños et al., 1993), working in the Los Tuxtlas region, found that plant number was more associated with yield than ear weight. Bolaños & Barreto (1991) and Bolaños et al. (1993) did not find a strong relationship between maize yield and plant density; they did, however, find a linear relationship between plant density and ear density, a component which had a strong association with yield. Triomphe (1996) found only low to moderate associations between yield and either plant density or number of ears per plant.

Impact on Maize Yield of Maize Management Factors

Agronomic monitoring generated data on the following maize management factors: maize variety, planting date, planting density, weediness, and burning. Their effects on maize yield were tested. Specifically, the impact of continuous variables (e.g., density, average weediness) on maize yield were examined by grouping together those plots where the variable was either at low, medium, or high levels, and analyzing differences among the least square means of yield. For discrete variables (e.g., maize variety, burning), means comparisons were made for yield between groups of plots using the alternative management practices.

Though correlations of yield and management factors (Table 4-16) typically were relatively low or non-existent, they did point to the relative importance of maize plant density and weediness as factors which help to explain maize yield.

1. Planting date

Differences in planting dates were not associated with maize yield differences in either of the 2 yr (Table 4-17). The absence of such differences may be caused by the fact that planting dates clearly varied among villages due to the variability in rainfall patterns. In fact, in 1996 there were moderately positive correlations between planting date and yield within three of the study villages, though there was no overall correlation.

Table 4-16. Average maize management factors (standard deviation in parenthesis) and their correlation (r) to maize yield (p-value in parenthesis).

	1995		1996	
Variable	Mean (SD)	r (p-value)	Mean (SD)	r (p-value)
Date of planting (from 1st)	15 (9)	-0.104 (0.217)	12 (6)	0.147 (0.144)
Date of flowering	70 (7)	-0.177 (0.040)	70 (8)	-0.016 (0.875)
Hills ha^{-1}	11 480 (2 830)	0.184 (0.037)	12 370 (3 600)	0.050 (0.627)
Plants ha^{-1}	32 470 (8 430)	0.374 (<0.001)	33 050 (7 350)	0.041 (0.693)
Plants hill^{-1}	2.9 (0.6)	0.184 (0.029)	2.8 (0.6)	0.059 (0.569)
Weediness-early †	2.0 (1.3	-0.218 (0.014)	1.8 (1.0)	-0.045 (0.651)
Weediness-late‡	2.1 (1.3)	-0.461 (<0.001)	2.3 (1.3)	-0.478 <0.001)

† Mean of weediness scores at maize planting and at 3 WAP.

‡ For 1995, mean of weediness scores at 6 WAP maize and at maize flowering. For 1996, weediness score at flowering.

Table 4-17. Least square means of maize yield as affected by management in 1995 and 1996.

	Grouping of fields by level of management variability					
	1995			1996		
Variable	Low	Medium	High	Low	Medium	High
	------------------ kg ha^{-1} ------------------					
Plants ha^{-1}	970a†	1 050a	1 400b	1 030ab	1 010a	1 300b
Plants hill^{-1}	970a	1 070a	1 170a	1 070a	1 090a	1 310a
Weediness–late	1 220a	1 070ac	890bc	1 180a	1 200a	860b
Date of planting	1 370a	1 010a	950a	1 310a	1 000a	1 450a

† Means within a year followed by the same letter are not different by p-difference (p>0.10).

2. Planting density

Higher maize plant densities were clearly associated with higher grain yield in 1995. The least square mean of plots with plant density over 35 000 ha^{-1} was 1450 kg ha^{-1}, while that of plots with density less than 30 000 ha^{-1} was 970 kg ha^{-1} (p=0.003; Table 4-17). In 1996, the density effect was not as obvious, as there was no difference between the lowest and highest density groups (p=0.310); however, the higher-density plots yielded more than plots with plant density between 30 000 and 35 000 plants ha^{-1}. A similar effect was found for hill density in 1995 but not in 1996. The weakness or absence of density response in 1996 was probably at least partly related to the inclusion of Salto de E. in the study. In Salto de E., higher plant densities were associated with lower yield (r= -0.465, p=0.081). For other villages, within-village correlation of maize plant density to grain yield was either positive or insignificant. No maize grain yield difference was associated with the number of plants per hill, a variable that could indicate intra-hill competition.

3. Weediness

Average weediness evaluations on a scale of 0 to 6 remained relatively constant throughout the growing season, varying from 1.9 (1995) or 1.8 (1996) at 3 WAP to 2.2 (1995) or 2.3 (1996) at flowering. Lower weediness scores were clearly associated with higher yield in 1995 (Table 4-17). Plots with early-season scores below 1.5 (on a scale of 6) yielded an average of 1200 kg ha^{-1}, while those with high scores (over 3) yielded 920 kg ha^{-1} ($p=0.048$). The effect was similar in the late season ($p=0.004$).

In 1996, plots scoring 4, 5, or 6 (on the scale of 6) at flowering yielded over 300 kg ha^{-1} less than plots with less weed infestation (Table 4-17). The negative impact of weeds on maize yield in the humid tropics is, of course, not surprising. Yield losses from weed growth in tropical maize production have been estimated to be from one-fourth (Parker and Fryer, 1975) to one-half (Brewbaker, 1966). The impact of weeds has been considered especially severe in the humid tropics where high temperatures and humidity favor weed growth (Olonuga and Akobundu, 1983).

Though it would seem that early-season weediness score should more consistently be associated with maize yield difference, this was not the case. The higher correlation between yield and late-season score is most likely an artifact produced by the methodology. In the early season, weediness measurements tend to fluctuate greatly due to timing of weedings. Monitoring visits, including the weed biomass taken at 3 WAP typically did not capture the highest weed infestation in the plots since visits were made at fixed time intervals. At any early-season visits, weeding may have just been performed in one plot, while in the next plot weeding may be conducted later that week. Of note, due to variability in the thoroughness of farmers' weeding, the number and timing of weedings described weed pressure less accurately than did average weediness.

4. Burning

No yield difference was found between plots where burning had taken place prior to summer maize planting and those where no burning had taken place (p=0.646 and 0.987 for 1995 and 1996, respectively). This is not surprising due to large variability among fields, a factor confounded with the burning practice.

Impact on Maize Yield of Environmental Factors

As with *Mucuna* biomass, the study was less able to quantify the impact on maize yield of environmental variables than for management variables.

1. Soil and slope

Though field observations suggested that maize growth and yield was inferior in fields with slope, no such yield difference was found (p=0.367). Moreover, soil P, K, and pH were either relatively poorly or not at all associated with yield. Similarly, Bolaños and Barreto (1991) in Central America and Eilittä (1992) in southwestern Nigeria found that measured soil factors were poorly associated with yield. Absence of such association in the analyses does not, of course, mean that maize growth was not impacted by soil fertility. In fact, field observations support a strong impact of soil fertility on maize yield. Nitrogen deficiency symptoms were common, and were manifested either as altered leaf color, increased leaf senescence (Lemcoff and Loomis, 1986), or delayed development (Bonaparte, 1975; McCullough et al., 1994; Tollenaar et al., 1997). Generally low maize yield and maize biomass production indicate the importance of soil factors.

2. Pest and disease

Maize grain yield was clearly affected by incidence of pest and disease. Harvest measurements of unusable ears and partially damaged ears were associated with maize grain yield differences (Table 4-18). In plots where more than 15% of the ears were unusable, maize yield was only 63 and 83% of the other plots in 1995 and 1996, respectively. Plots with more than 40% of partially damaged ears yielded only 73 and 78% of plots where less than 30% of ears were damaged.

Table 4-18. Maize yield least square means as affected by pest and disease damage groups.

Variable	Year	Damage group		
		Low	Medium	High
		- - - - - - - - - - - kg ha^{-1}	- - - - - - - - - -	
% unusable ears	1995	1 190a†	1 190a	750b
	1996	1 430a	1 230a‡	730b
% partially damaged ears	1995	1 180a	1 180a	920b
	1996	1 360a	1 150a	1 160a

† Means within a row followed by the same letter are not different by p-difference ($p>0.10$).

‡ p-difference Medium vs. High: 0.106

3. Date to 70% tasseling

Time to flowering is closely associated with temperature; as significantly slower leaf expansion occurs in cooler climates (Fischer and Palmer, 1984). Thus, date to 70%

tasseling is considered to be an environmental factor. In 1995, later tasseling was associated with higher yield, while in 1996, later tasseling was associated with a trend for lower yield. In 1995, the longer time to flowering in San Fernando (the coolest village) was associated there with increased yield, but the yield response may have been caused mainly by higher fertility. As discussed earlier, delayed development is also associated with soil fertility (Bonaparte, 1975; McCullough et al., 1994; Tollenaar et al., 1994); such a phenomenon was evident in the field, and could perhaps be the cause of slight negative correlation between chlorophyll content and time to 70% tasseling ($r=-0.151$, $p=0.071$).

Village-level Effects on Maize Yield

In the study, village represented a maize growing environment. There were clear differences among the villages in both management and environmental variables. Such differences are presented in Table 4-19. Moreover, there were differences among villages in the length of the time that farmers had used *Mucuna*, and in the type of system that farmers were using.

Yet such management and environmental differences were not associated with any clear yield differences among villages. Overall, the village effect on maize yield was non-significant for both 1995 ($p=0.183$) and 1996 ($p=0.750$). However, for 1995, comparisons of least square means revealed that average maize yield was lower in Santa Rosa (840 kg ha^{-1}) than in the other villages ($p=0.062$, 0.082, and 0.147 with La Candelaria, Soteapan, and San Fernando, respectively). Moreover, the yield distribution within villages seemingly differed. In 1995 San Fernando, and to a lesser extent Soteapan, had a higher share of plots with relatively good yield while Santa Rosa had a large share of plots with low yields (Table 4-20). In 1996, San Fernando again exhibited a large number of higher yields. Santa Rosa's higher yield in 1996 is partly explained by the fact that most of the low-yielding plots of 1995 (17 of the 20 plots that yielded less than 1 t ha^{-1}) were not included in the study in 1996 since the farmers indicated that they would no longer plant *Mucuna.*

Table 4-19. Least square means of maize yield and management factors in 1995 as affected by village.

Variable	La Candel.	Santa Rosa	Soteapan	San Fernando
Grain (kg ha^{-1})	1 140a†	840b	1 180a	1 230ab
Ears ha^{-1}	17 880a	15 650a	17 940a	1 7650a
Unusable ears (%)	11a	18b	6ac	2c
Part. damaged ears (%)	39ab	46a	36c	33c
Ear grain weight (g)	70a	62a	69a	66a
Plants ha^{-1}	31 750a	31 040a	34 390a	34 560a
Weediness–early	1.5a	2.1ab	2.7b	1.6a
Weediness-late	1.8a	2.4a	2.3a	1.9a

† Means followed by the same letter are not different by p-difference ($p>0.10$).

Trends in the data indicate possible causes for the poorer performance of Santa Rosa in 1995. First, the difference may have been caused by Santa Rosa's higher disease and pest incidence, and lower average ear grain weight (perhaps partly due to pest and disease incidence) though no statistically significant differences were found compared with other villages. Second, weediness in Santa Rosa's fields tended to be higher than in the neighboring La Candelaria, which may have affected the yield level.

Table 4-20. Percentiles of maize yield in the study villages in 1995 and 1996.

Percen-tile†	1995				1996			
	kg ha^{-1}							
	La Cand.	S. Rosa	Sot.	S. Fern.	La Cand.	S. Rosa	S. Fern.	Salto
100	1 980	2 550	2 470	3 070	1 860	2 940	2 460	1 980
75	1 450	1 110	1 630	1 830	1 080	1 940	1 940	1 530
50	1 100	730	1 180	1 190	790	1 330	1 510	1 270
25	820	520	730	630	480	780	970	610
0	490	50	220	90	150	50	31	150
V mean (SD)	1130 (410)	860 (540)	1190 (560)	1270 (760)	820 (410)	1390 (740)	1390 (690)	1120 (550)

† Percentage of plots with lower yield.

In 1996, no maize yield differences were found among villages although yields tended to be lowest in La Candelaria, highest in Santa Rosa and San Fernando, and intermediate in Salto de E. The trends for higher yields in Santa Rosa and San Fernando that year seem to be associated with lower plant density, lower share of partially damaged ears, higher share of plants with ears, and higher ear grain weight.

Summary and Conclusions

The agronomic monitoring portion of this study quantified both maize and *Mucuna* production, as well as the management and environmental conditions of such production, in a large number of fields. The assistance of farmers during times of intensive data gathering allowed data collection from a large number of fields in logistically difficult conditions. The monitoring was not as successful in quantifying the impact of management and environmental variables on the performance of the maize-

Mucuna systems in the region. Though the impact of several management factors on maize and *Mucuna* growth was quantified, the analysis was not always conclusive. Finally, the impact of many environmental factors could only poorly be characterized.

Mucuna Biomass and Factors Affecting *Mucuna*'s Growth

This study documents the relatively low *Mucuna* biomass in the study region, which in 1996 averaged slightly over 4 t ha^{-1} including the mulch component. This average biomass was well below that of 7 t ha^{-1} obtained in the sole-cropped, experimental conditions of this study (Chapters 6 and 7). The average N content of the biomass was slightly over 100 kg ha^{-1}.

This study was able to elucidate the impact of environment factors on *Mucuna* biomass only poorly. It is clear, though, from field observations that soil fertility clearly controls some of the large between-field variability in *Mucuna* performance, and some of the apparent differences among villages. Research results elsewhere support this observation (Tian et al., 1998; Tian and Kang, 1998).

The most striking finding related to *Mucuna* productivity was the large variability in the *Mucuna* biomass, and the large number of fields where no positive impacts of *Mucuna* on maize yield could be expected due to either very low biomass and/or the continuation of the burning practice. Such high variability in on-farm conditions, particularly in more difficult environments, has been one of the factors cited in the literature to explain the poor adoption of green manure crops (Becker et al., 1995; Drechsel et al., 1996). However, in the study of spontaneously-adopted *Mucuna* system in the Atlantic Honduras, variability in *Mucuna* biomass was low. Relatively low biomasses in the region are especially worrisome in System B, where a long time lag occurs before the following maize planting, and larger losses of nutrients are likely. Recent research suggests that N may be lost through several avenues: First, through the elimination of mulch during the dry season; second, through N volatilization in surface mulch systems (e.g., Janzen and McGinn, 1991); and third, through mineralization of N prior to main corp planting. In the maize-*Mucuna* System B in Veracruz, *Mucuna* is on the soil surface approximately 6 mo prior to the following summer maize planting.

Some of the variability in biomass is explained by management factors, namely *Mucuna* planting density and date as well as the choice of maize-*Mucuna* system. *Mucuna* planting in the region takes place quite late, and planting is done at densities well below those utilized under most experimental conditions. In comparison to the Atlantic Honduras, where a long growing season may compensate for management differences (Buckles et al., 1998), the shorter growing season in Veracruz may not allow for such compensation. Causes and effects in this regard are relatively hard to establish in the study area, as several of the sub-optimal *Mucuna* management practices which result in lower biomass can be seen to result from low farmer interest in *Mucuna.*

It is ironic that *Mucuna*'s growth is more limited in environments where its beneficial impacts are most needed: i.e., in low-producing, marginal conditions where farmers' possibilities for acquiring external inputs, including fertilizers, are limited. Such an observation is, of course, quite logical, as many of the same factors that limit yields for the main crop also impact negatively the growth of *Mucuna*. Experiments in 25 environments in Central America have shown that residue-loading from crop stover is often inadequate in the marginal environments for year-round protective mulch layer

(Barreto, 1994); such results imply that establishing resource-conserving practices may be hardest in regions where they are most needed.

Maize Productivity and Affecting Factors

The findings on maize yield components and factors affecting maize yield are not surprising. The sensitivity of maize to environmental stresses during flowering makes it susceptible to barrenness and low ear weight. In this study, the total number of ears, ears per plant, and ear weight were yield components that were strongly associated with maize yield. The number of plants was typically associated with maize yield only poorly, presumably due to the high variability in the number of ears produced per plant.

Of the management factors, weediness and planting density were seemingly associated with lower yields. Though the findings lend support to the notion that increased planting density would probably result in higher yields, they also – together with field observations – affirm the importance of changing the planting pattern. Though no differences in maize yield were found between groupings that had a low, medium, or high number of maize plants per hill, the high barrenness and field observations strongly suggest that the currently employed number of plants per hill is excessive, while the number of hills per hectare could be increased. The typical smallholder planting pattern, with high number of plants per hill (averaging almost three), typically resulted in production of only 1-2 ears per hill. Farmers report that they have decreased the number of plants per hill during the past decades as a response to decreased soil fertility. Planting two plants per hills would, however, require seed with reliable germination.

In the following chapter, impact of *Mucuna* on maize yield will be discussed.

CHAPTER 5
AGRONOMIC MONITORING OF THE FARMER-MANAGED MAIZE-*MUCUNA* SYSTEMS: II. THE IMPACT OF *MUCUNA* ON SUMMER MAIZE YIELD

Introduction

A primary goal of the study was to evaluate whether maize grain yield in the region is affected by the presence of *Mucuna* in the cropping system. Such an impact could be negative, stemming from *Mucuna*'s competition with maize, or positive, presumably deriving primarily from *Mucuna*'s N contribution and cover effects.

The essential challenge to analysis of the observational data therefore is: can *Mucuna*'s effects be separated from the effects of the particular environmental and management conditions where each of the two treatments were located? Two possibilities exist. *Uncontrolled management and/or environmental differences between the Mucuna and no-Mucuna plots could have created the false impression that Mucuna impacts maize yield* (Alternative 1). An example of how this could happen is if higher maize plant density occurred in the *Mucuna* plots, which would then be associated with a higher maize yield. On the other hand, *confounding management and/or environmental differences may have hidden 'real' differences between Mucuna and no-Mucuna plots* (Alternative 2). For example, the *Mucuna* plots might have yielded more, were it not for their being assigned to areas of lower soil fertility.

Methodology of the agronomic monitoring was presented in Chapter 4. In the following, the possible impact of *Mucuna* on maize grain yield will be examined by study year, and by the length of *Mucuna* use in the monitoring plots. These findings will be discussed in light of the two alternatives presented above. The chapter will conclude by examining factors behind the small or non-existent impact of *Mucuna* on maize yield.

Results

Overview of *Mucuna*'s Impact on Maize Yield

To summarize key findings in 1995, the agronomic monitoring data demonstrated no overall maize yield differences between *Mucuna* and no-*Mucuna* plots (Table 5-1). The treatment performance did, however, vary by village. In La Candelaria, *Mucuna* plots yielded less maize, while in Santa Rosa, *Mucuna* plots yielded more than the no-*Mucuna* plots. In the other two villages, maize yields did not differ significantly between the *Mucuna* and no-*Mucuna* plots. In 1996, no overall differences were found, and treatment performance did not vary by village.

Table 5-1. Analysis of variance of maize yield in 1995 and 1996.

Effect	1995 p-value	1996 p-value
Village	0.183	0.750
Field (village)	0.001	0.001
Mucuna	0.385	0.113
Village x Mucuna	0.015	0.342
Field x treatment (village)	0.001	<0.001
Replication (village x field)	0.002	0.011

As discussed earlier, environmental variables were not significantly associated with yield differences. Analyses conducted for soil P and K showed no significant differences between *Mucuna* and no-*Mucuna* plots either generally, nor in any of the villages; soil N was not measured. For that reason, the discussion will focus on the two maize management variables in which intra-field differences could be expected, and which were generally associated with yield differences: i.e., maize plant density and weediness. The results of the corresponding ANOVA are presented in Table 5-2.

The Impact of *Mucuna* on Maize Yield in 1995

1. Analysis of all monitoring plots in 1995

When all fields of 1995 were analyzed together, no significant treatment differences were found ($p=0.385$; Table 5-2). However, the 1995 results show clear treatment by village interaction ($p=0.015$). In that year, La Candelaria's no-*Mucuna* plots outyielded *Mucuna* plots by about 320 kg ha^{-1} ($p=0.010$), whereas in Santa Rosa the *Mucuna* plots outyielded no-*Mucuna* plots by 290 kg ha^{-1} ($p<0.001$; Table 5-3). Such differences are interesting because in Santa Rosa most plots were in their second and third year of *Mucuna* cultivation, where positive effects of *Mucuna* on grain yield may be more likely. In La Candelaria, on the other hand, half of the plots were first-year *Mucuna* plots where one would expect either no or negative effects on maize grain yield. In Soteapan and San Fernando, there were no clear differences in treatment performance.

Analyses of management variables in all plots of 1995 showed no overall treatment differences in the management variables (Table 5-2). No-*Mucuna* plots had a tendency for higher density ($p=0.144$), but the difference between the treatments was small (850 plants ha $^{-1}$). Consequently, there appears to be no evidence of confounding differences in management that may have hidden 'real" *Mucuna* impacts ('Alternative 2'). On the contrary, the data lends support to the existence of phenomenon outlined in Alternative 1, the existence of management variables that may have caused apparent impacts of *Mucuna*. When the treatment performance is analyzed by village, it is clear (Table 5-3) that the higher yields were associated with lower weediness in both La Candelaria's no-*Mucuna* plots ($p<0.001$) and Santa Rosa's *Mucuna* plots ($p=0.015$). In both cases, higher yields were also associated with a trend toward higher plant density. In San Fernando and Soteapan, where there was no significant difference between maize yield in *Mucuna* and no-*Mucuna* plots, lower weediness score and higher plant density (Soteapan) and higher plant density (San Fernando) were associated with the trend of higher yield.

2. Analysis of first-year plots in 1995

There was no general impact of *Mucuna* among the first-year fields in the 1995 data set ($p=0.298$; Table 5-2). Treatment performance did, however, vary by village ($p=0.066$), but only in Santa Rosa did maize yield differ in the *Mucuna* (210 kg ha^{-1}) and no-*Mucuna* plots (530 kg ha^{-1}; $p=0.026$).

In these first-year *Mucuna* fields, no-*Mucuna* plots had a higher hill density (by 1110, $p=0.098$) and plant density per hectare (by 4860; $p=0.016$; Table 5-4). This, however, resulted in no yield advantage for these no-*Mucuna* plots ($p=0.298$). Could the presence of *Mucuna* have "compensated" for the lower maize density in *Mucuna* plots (Alternative 2)? Though it has been shown that in some instances non-legumes benefit from the associated legume during the same growing season (Agboola and Fayemi, 1972), it is unlikely that *Mucuna* would have beneficial impacts in its first year of planting due to the late *Mucuna* planting dates. The difference in maize yield between *Mucuna* and no-*Mucuna* plots in Santa Rosa was based on data from only two fields and could not be associated with any management factors.

3. Analysis of second and third-year plots in 1995

There were no overall *Mucuna* effects on maize yield in second-and third-year *Mucuna* plots (p=0.899; Table 5-2). However, treatment performance did vary by village (p=0.095), and maize yield in *Mucuna* and no-*Mucuna* plots differed in three of the four villages (Table 5-5). Maize yield in plots with *Mucuna* intercrop was less in La Candelaria (p=0.046), but greater in Santa Rosa (p=0.001), and Soteapan (p=0.004).

Maize plant density and weediness were not different across villages in second- and third-year plots (Table 5-2), but there were treatment by village interactions (Table 5-5). In La Candelaria, lower maize yields in *Mucuna* plots were associated with trends, but not with significant differences, in the average weediness scores. In Santa Rosa, the higher yields in *Mucuna* plots were associated with trends for higher density and lower weediness. In Soteapan, the slightly higher maize yield in *Mucuna* plots was associated with higher plant density (p=0.003), hill density (p=0.020), and number of plants per hill (p=0.018). In contrast, in San Fernando it was the no-*Mucuna* plots with the clearly higher density. Higher yields were not associated with these differences in San Fernando, however.

Table 5-2. The p-values for *Mucuna* treatment and treatment by village interaction effects on maize yield and management for subsets of the fields that were monitored.

	1995 (all plots)		1995 (1^{st} year)		1995 (2^{nd} + 3^{rd} year)		1996 (all plots)		1996 (2^{nd} + 3^{rd} year)	
Variable	Trt	V*trt	Trt	V*trt	Trt	V*trt	Trt	V*trt	Trt	V*trt
Maize yield (kg ha^{-1})	0.385	0.015	0.298	0.066	0.899	0.095	0.113	0.342	0.220	0.500
Hills ha^{-1}	0.344	0.002	0.098	0.723	0.968	0.001	0.283	0.291	0.234	0.277
Plants ha^{-1}	0.144	0.007	0.016	0.191	0.931	<0.001	0.128	0.085	0.218	0.086
Weediness–early	0.348	0.075	0.745	0.480	0.254	0.276	0.095	0.674	0.093	0.722
Weediness –late	0.475	0.062	0.237	0.243	0.905	0.225	0.140	0.111	0.675	0.381

Table 5-3. Maize yield and management factors as affected by *Mucuna* treatment in the study villages in all plots of 1995.

Variable	La Candelaria		Santa Rosa		Soteapan		San Fernando	
	Mucuna	No *Muc.*	*Mucuna*	No *Muc.*	*Mucuna*	No *Muc.*	*Mucuna*	No *Muc.*
Maize yield (kg ha^{-1})	980a†	1 300b	1 000a	710b	1 230a‡	1 150a	1 230a	1 300a
Hills ha^{-1}	11 690a	12 320b	12 150a	11 810a	12 630a	11 030b	8230a	10 200b
Plants ha^{-1}	30 330a§	33 180a	31 520a	30 560a	37 130a	31 180b	29 330a	40 050b
Weediness – early	1.8a	1.3b	2.0a	2.2b	2.5a	2.9b	1.4a¶	1.8a
Weediness - late	2.1a	1.4b	2.1a	2.8b	2.0a	2.6b	1.9a	1.9a

† Means within a village and row followed by the same letter are not different (p>0.10).
‡ p=0.143
§ p=0.118
¶ p=0.108

Table 5-4. Maize yield and selected management factors as affected by *Mucuna* in the first-year plots in 1995.

Variable	*Mucuna* plots	No-*Mucuna* plots	p-value
Maize yield (kg ha^{-1})	1 110	1 190	0.298
Hills ha^{-1}	10 650	11 760	0.098
Plants ha^{-1}	29 990	34 850	0.016

The Impact of *Mucuna* on Maize Yield in 1996

1. All monitoring plots

In 1996, maize yield tended to be greater in no-*Mucuna* than in *Mucuna* plots (p=0.113; Table 5-2) but the magnitude of the difference was small (40 kg ha^{-1}). The trend for slightly higher yield in the no-*Mucuna* plots was associated with a trend for slightly higher density (820 plants ha^{-1}, p=0.128), and slightly lower early-season weediness score (by 0.2; p=0.095).

2. Second and third year plots

No differences (p=0.220) between *Mucuna* (1160 kg ha^{-1}) and no-*Mucuna* (1200 kg ha^{-1}) were found and there was no treatment by village interaction in 1996 (Table 5-2). There was a small difference in early-season weediness ratings between the *Mucuna* (1.9) and no-*Mucuna* plots (1.6; p=0.093). There was no treatment effect on plant density.

Table 5-5. Maize yield and selected management factors as affected by *Mucuna* in second and third year plots in 1995.

	La Candelaria		Santa Rosa		Soteapan		San Fernando	
Variable	*Mucuna*	No *Muc.*	*Mucuna*	No *Muc.*	*Mucuna*	No *Muc.*	*Mucuna*	No *Muc.*
Maize yield (kg ha^{-1})	910a†	1 380b	1 070a	790b	1 370a	1 300b	890a	880a
Hills ha^{-1}	10 910a	10 990a	12 300a	11 860a	14 290a	11 310b	7 430a	9 900b
Plants ha^{-1}	29 520a	29 380a	31 920a	30 820a	42 520a	31 450b	28 800a	43 450b

† Means within a village and row followed by the same letter are not different ($p>0.10$).

Discussion: Explaining the Lack of Strong *Mucuna* Effect

These data suggest that yield differences between *Mucuna* and no-*Mucuna* plots were typically associated with management differences in these plots. Simultaneously, it seems that the absence of yield differences between *Mucuna* and no-*Mucuna* plots is not associated with the presence of management differences that would tend to hide real impacts of *Mucuna* on maize yield. It seems likely, therefore, that most of the variability in maize yield between *Mucuna* and no-*Mucuna* plots is caused by within-field variability in management rather than by *Mucuna*. It is, however, also evident that the results of the analysis are not fully conclusive, and management differences may have hidden *Mucuna* impact to some extent.

At the very least, the analysis clearly demonstrates that *Mucuna*'s impact on maize yield is not strong. This discussion is devoted to exploring reasons for the lack of strong impacts from *Mucuna*. Only a limited amount of data are available for this analysis, thus the ideas presented are partially speculative.

Analysis of the agronomic monitoring data suggests that, in the Los Tuxtlas region, the lack of a demonstrable strong impact of *Mucuna* on maize yield is attributable to at least five factors:

- The recency of *Mucuna* use in the area
- The (expected) low and delayed impact of System A on summer maize
- The practice of burning crop residues prior to summer maize planting
- The relatively low nutrient content of *Mucuna*, and

- The large potential for nutrient losses in System B.

In the following, each of these factors is discussed in turn.

1. The recency of *Mucuna* use

Extension efforts did not start in the region prior to 1992, and most farmers in the study planted *Mucuna* in the monitoring plots for the first time between 1992 and 1995. The recency of *Mucuna* use in the region means that no longer-term soil benefits from *Mucuna* could have taken place yet. The effect of the recency of *Mucuna* use is compounded by the fact that in any given field farmers typically rotate the area under *Mucuna*. Thus, in relatively large portions of many fields, *Mucuna* is planted only for the first or second year, even though the farmer may have utilized *Mucuna* for a longer time. The hoped-for "accrued" benefits over time from *Mucuna* use are not realized in such cases.

2. Impact of past utilization of System A in the study fields

Mucuna's impact on summer maize yield can be expected to be small also because the study included fields where maize-*Mucuna* System A had been practiced in previous years. In those fields, *Mucuna* had been slashed just prior to the winter maize planting, and it can be expected that most of *Mucuna*'s beneficial effects would have accrued to the following winter maize. Due to rapid decomposition of *Mucuna*, high rates of N availability, up to 80%, have been reported to the first catch crop (van Noordwijk et al., 1995); that being the case, impact on summer maize in these System A fields would, indeed, be very small.

3. The practice of burning crop residues prior to summer maize planting

The maximum content of N in *Mucuna* biomass is a poor estimation of its N contribution to the following summer maize in the fields where crop residues are burnt prior to summer maize planting. Most farmers in the study villages still continue the burning practice, which may limit the effectiveness of the maize-*Mucuna* system. Several issues are relevant in this regard. First, as discussed in Chapter 3, burning often takes place far in advance of the growing season and resulting ashes often are blown by winds prior to the beginning of the rains. Second, the practice of burning varies greatly as discussed in Chapter 3. Third, as discussed in Chapter 2, roots of *Mucuna* may be an important avenue for N storage, especially in low-fertility soils (Tian and Kang, 1998). Finally, though it is clear that burning volatilizes most of the N present in the above-ground biomass (Sanchez, 1976), positive impacts of *Mucuna* have been reported, even in the presence of burn (Becker et al., 1998; Vine, 1953, cited in Carsky et al., 1998).

The practice of *Mucuna* residue burning would presumably be particularly harmful in System B fields. In System A fields most of the *Mucuna* biomass has already decomposed by the time the fields are burnt in April or May. The burning in System B would volatilize a great deal of the N present in the *Mucuna* biomass. In both systems, it likely reduces or negates many of the other, cover-related impacts of *Mucuna*. The June 1997 sampling of mulch in System B fields in La Candelaria and Santa Rosa demonstrated the negative consequences of burning (Table 5-6). Though the N and P concentrations of the remaining mulch differed little between the burnt plots and those that had not been burnt, the non-burnt plots averaged a great deal more biomass, and therefore had a higher content of nutrients. Across *Mucuna* and no-*Mucuna* plots, the mulch in plots that had not been burnt contained almost five times as much N and P as in the plots that had been burnt.

Table 5-6. Mulch biomass, N, and P concentration and content as affected by the practice of burning in June 1997.

Variable	With burn	Without burn	p-value
Mulch (kg ha^{-1})	1 280	5 260	<0.001
Nitrogen (%)	1.16	1.14	0.953
Phosphorus (%)	0.09	0.10	0.609
Nitrogen (kg ha^{-1})	14	64	<0.001
Phosphorus (kg ha^{-1})	1.2	5.9	<0.001

4. Relatively low *Mucuna* nutrient content

Analysis of *Mucuna* biomass and biomass fractions in 1996 demonstrated a relatively low average nutrient content, marked by great variability.

The average N content in *Mucuna* fractions was only 110 kg ha^{-1}, greatly below the 295 kg ha^{-1} reported in literature in the maize-*Mucuna* system in the Atlantic Honduras (Triomphe, 1996). A clearly lower share of the N is tied in the mulch component in Veracruz; 45% in comparison to 58% in the Honduran case (excluding weeds). Unlike in the Honduran system where apparently there are almost no weeds at slashing time, a significant amount of total N, about 8%, was in the weed fraction. Sanginga et al. (1996a) reported N contents of 313 kg and 166 kg at 12 wk of growth from farmer-managed fields in Benin. The highest plot-level total N content (including weeds) was 390 kg ha^{-1}, in a relatively fertile lower slope in a field which had not been burnt, while the lowest was 15 kg ha^{-1}. This latter biomass was attained in a field where *Mucuna* was planted late and slashed early to plant winter maize.

In at least one-fourth of the plots, little impact of the *Mucuna* mulch could be expected due to its extremely low N content. If the N content of the *Mucuna*-mulch fraction without the pod is considered (since the pods are either collected or utilized for self-seeding), in one-fourth of the plots N content was less than 50 kg ha^{-1} while in the lowest 10% it was less than 20 kg ha^{-1}.

Nutrient concentration: In the biomass fractions, N and P concentrations (Table 5-7) were comparable to those described in the literature, though differences in fractionation make direct comparisons difficult. The highest nutrient concentration was in leaf fraction, followed by pod and weed. The nitrogen concentration in the mulch fraction is lower by 0.7-0.8% than those reported in the rotational system of Atlantic Honduras (Triomphe, 1996). This could be caused by both the recency of *Mucuna* use in Veracruz (relatively little material of *Mucuna* origin in the mulch), by burning (more of the woody materials remain), and by less leaf-shedding during the growing season in the intercropped system (due to less self-shading).

Further analysis of *Mucuna* nutrient concentration data was directed toward discerning possible village, treatment, and system effects. There were no village and treatment effects on *Mucuna* nutrient concentration in most fractions. However, weed N concentration varied by village, presumably due to differences in weed populations. In addition, stem N concentration was higher, at 1.96%, when *Mucuna* was slashed just prior to winter maize planting than when *Mucuna* matured in the fields (1.62%; p=0.008).

Lower N concentration in comparatively more mature stem tissue in System B can be expected due to increased lignin and structural carbohydrates.

Table 5-7. Average N and P concentration (standard deviation in parentheses) in the biomass fractions in 1996

Biomass fraction	N	P
	---------------- %	---------------------
Leaf	4.84 (0.48)	0.39 (0.62)
Stem	1.73 (0.39)	0.13 (0.08)
Pod	3.46 (0.38)	0.27 (0.05)
Mulch	1.89 (0.58)	0.14 (0.06)
Weed	2.15 (0.44)	0.19 (0.06)

Impact of system on nutrient content: The total average *Mucuna* N content of System A, 105 kg ha^{-1}, was only about 23% less than that of System B, 136 kg ha^{-1} (p=0.013; Table 5-8). Such results are close to the typically reported averages of 100 kg ha^{-1} of N in green manure legumes (Peoples and Craswell, 1992). The difference in N derived from *Mucuna* fractions, or from *Mucuna*-pod fractions was smaller (16% and 9% respectively), reflecting the large N contribution of weeds in System B. No statistically significant difference between systems was detected for leaf, stem, or weed fractions. Nitrogen content of leaf and stem fractions tended to be higher in System A, presumably due to leaf shedding and stem lignification in the more mature tissue of System B. The weed fraction's N content tended to be almost three times higher in System B. Very similar trends are evident for P. All three fractions contained approximately 30% less phosphorus in System A than in System B. As discussed earlier, most System A plots were located in Salto de E. where *Mucuna* growth was more luxuriant than in the other villages.

5. The potential for relatively high losses of nutrients

Data on nutrient concentration and content in the maximum *Mucuna* biomass reveal relatively little about the actual contribution of the nutrients in the biomass to the soil or to subsequent crops. Nutrients may be lost through several avenues. First, mulch may be eliminated or transported out of the field. Carsky et al. (1998) have estimated that in regions with 3- to 4-mo dry period, a large proportion of *Mucuna* biomass may be eliminated. In Veracruz, animals may browse in the fields during dry season, and high winds which carry off *Mucuna* leaves, are common. Second, nutrient mineralization may take place prior to the next crop's planting. In reviewing TROPSOILS research conducted in subhumid Brazil, Lathwell (1990) found rapid accumulation of soil inorganic N in the first 40 to 60 d after incorporation of the mulch; such mineralization can be expected to be more rapid with incorporation than if residues are left as surface mulch.

Finally, recent evidence points to the importance of ammonia volatilization from surface-applied mulches (Larsson et al., 1998; Glasener and Palmer, 1995; Janzen and McGinn, 1991; Hargrove, 1988). Hargrove (1988) argues that highest losses are expected in windy and hot conditions, and in soils at or near field capacity that are undergoing rapid drying. The high temperatures and winds in the dry season in the study area would appear to act in favor of volatilization; however, the low rainfall may counteract this effect to a degree.

Table 5-8. N and P content of biomass fractions as affected by maize-*Mucuna* system in 1996.

	N content			P-content		
Biomass fraction	Syst. A†	Syst. B‡	System p-value	Syst. A†	Syst. B‡	System p-value
	----- kg ha^{-1} -----			---- kg ha^{-1} -----		
Leaf	26	22	0.260	1.6	2.1	0.180
Stem	16	9	0.446	1.1	0.7	0.238
Pod	20	31	0.041	1.7	2.6	0.004
Mulch	36	55	0.005	2.1	3.8	0.026
Weed	7	20	0.414	0.9	1.8	0.855
Total	105	136	0.013	6.4	11.0	0.002
Mucuna	98	116	0.009	5.7	9.2	0.002
Mucuna-pod	78	86	0.024	4.6	6.6	0.009

† At slashing.
‡ At maturity.

What, then, may be the expected additional N contribution to maize from *Mucuna* in Systems A and B, given that the average N content of *Mucuna*-mulch component (excluding pod), is 78 and 86 kg ha^{-1} for the Systems A and B, respectively?

Most experimental data available are from systems where *Mucuna* is sole-cropped and the following crop is planted soon after slashing *Mucuna*, more closely resembling System A. Lathwell (1990) reports that in one such system 40 to 77% of *Mucuna* N was recovered by subsequent maize when *Mucuna* was incorporated in soil. Higher recovery rates occurred in soils with low inorganic N. With an average recovery of 59%, recovery would be 46 and 51 kg ha^{-1} for Systems A and B, respectively.

However, most authors agree that recovery of N is relatively less when *Mucuna* is applied as surface mulch due to high losses. It has been suggested that recovery of N from surface-applied mulch may be only 15% on average (Lathwell, 1990); such contribution would be the equivalent of 12 and 13 kg N ha^{-1} in Systems A and B. Fertilizer substitution rates for *Mucuna* have been around 70 kg ha^{-1} in many experimental situations where *Mucuna* slashing was followed by main crop planting (Smyth et al., 1991; Yost et al., 1985; van Noordwijk et al., 1995).

Though this study did not focus on nutrient dynamics, it is clear that such dynamics are quite different for System A as compared to System B. Nutrient losses are more likely in System B, as in this system, up to 6 mo pass from the maximum *Mucuna* biomass and senescence until the planting of the next maize crop. As discussed in Chapter 3, environmental conditions also vary for the two systems. In System A, *Mucuna* is slashed, and maize is planted typically within 1 to 2 wk. Rainfall continues in the subsequent period. In System B, *Mucuna* leaves fall to the ground, where they remain over a period of many months when high temperatures and winds often prevail. The expected nutrient contribution takes place during the rainy summer season. Presumably the first heavy rains of the summer could cause leaching of the nutrients at a time when the maize root system is not well developed.

This study did not address the question of what impact the time lag in System B may have on nutrient recovery by the next crop, as it did not focus on the nutrient dynamics of the maize-*Mucuna* systems in the region. Increased yields due to *Mucuna* have been reported where there has been a long time-lag after *Mucuna* senescence (Ile et al., 1996).

Some preliminary work on the impact of the time lag was conducted. To examine change in nutrient concentration during the time lag, *Mucuna* leaf, stem, and pod fractions were collected prior to May slashing. Moreover, mulch samples were collected to find out whether any differences in mulch nutrient concentration and content between *Mucuna* and no-*Mucuna* plots persist through the dry season and until the summer maize planting in June. As discussed in Materials and Methods, such sampling was conducted only in 1996 following a particularly rainy dry season. As is clear in Table 5-9, the N concentration of leaf fraction in System B decreased by almost a third, while the other fractions' N content decreased only slightly. The largest changes were found in P concentration, especially that of the leaf fraction. Interpretation of these data must be guided by several caveats. First, one should note that decomposition was not accounted for and only visible fractions were collected; a part of the leaf fraction especially had already decomposed. For leaf and mulch fraction such average nutrient concentrations can therefore be considered only as rough indicators of concentration in the remaining biomass. Such sampling also provides only a static picture. For example, the measured mulch fraction at maturity had quite likely undergone an enrichment due to leaf shedding, and then a gradual decrease. As the sampling was conducted only once, it is impossible to estimate the effect of the particularly rainy dry season on the concentrations, though it can be expected that more leaching of nutrients from the fractions took place than normally. It is clear, however, that nutrient concentrations in System B have decreased prior to the summer cropping seasons, and that the concentrations presented here are more likely to be maximum, rather than average, nutrient concentrations. Of note, the mulch sampling of System B plots in June, conducted just before a typical maize planting time showed that despite the decreases in nutrient concentration during the dry season, mulch N concentration tended to be different in the *Mucuna* plots (1.43%) than in the no-

Mucuna (0.84%) plots (p=0.129; Table 5-10). Moreover, due to the much higher mulch biomass in the *Mucuna* plots, their average N content was 141%, (p=0.003) and P content 91% higher (p=0.016) than that of no-*Mucuna* plots.

Table 5-9. N and P concentration (standard deviation in parentheses) in System B plots at maturity and prior to slashing in May 1996.

	N			P		
Fraction	Maturity	May	% change	Maturity	May	% change
	- - - - - - - - % - - - - - - -			- - - - - - - - % - - - - - - -		
Leaf	4.89 (0.48)	3.54 (0.23)	28	0.44 (0.75)	0.14 (0.02)	68
Stem	1.62 (0.28)	1.10 (0.21)	17	0.13 (0.07)	0.08 (0.03)	38
Pod	3.38 (0.31)	3.56 (0.22)	5	0.27 (0.05)	0.22 (0.07)	19
Mulch	1.98 (0.55)	1.43 (0.66)†	7	0.15 (0.06)	0.12 (0.07)†	20

† in June

Table 5-10. Mulch biomass, N, and P concentration and content as affected by the *Mucuna* treatment in June 1997. Means include both burnt and non-burnt fields.

Variable	With Mucuna	Without Mucuna	p-value
Mulch (kg ha^{-1})	3 930	2 370	0.005
Nitrogen (%)	1.43	0.84	0.129
Phosphorus (%)	0.12	0.08	0.264
Nitrogen kg (ha^{-1})	53.00	22	0.003
Phosphorus (kg ha^{-1})	4.40	2.4	0.016

Conclusions

The impact of *Mucuna* on maize production could not be conclusively determined, though it was clear that *Mucuna*'s impact, positive or negative, could not have been great. The association between variability in yield and management factors in *Mucuna* and no-*Mucuna* plots seems in many cases quite convincing. It indicates that a great deal of the variability between *Mucuna* and no-*Mucuna* plots may, in fact, have been caused by within-field variability, and especially by difference in maize management between the *Mucuna* and no-*Mucuna* plots. Such a conclusion is supported by the relatively large share of variability in maize yield that is accorded to the purely locational effect in the ANOVA model, repetition within the field (1995: 16%, 1996: 5%). Similarly it seems that in those cases where apparent impacts of *Mucuna* on maize yield are absent, such a situation is not caused by the presence of management differences that "are hiding" true impacts of *Mucuna* on maize yield.

It is, however, clear that the results of the analysis are not fully conclusive. First, often only trends in management data support clear differences in yield in *Mucuna* and no-*Mucuna* plots, or contradictory differences exist. Second, differences in maize management between *Mucuna* and no-*Mucuna* plots may reflect farmers' adjustments to either perceived or hoped-for impacts of *Mucuna*. For example, a farmer may be planting *Mucuna* plots with higher density of maize in order to "harvest" the hoped-for positive impacts of *Mucuna*. Some factors, such as differences in weediness between *Mucuna* and no-*Mucuna* plots, may also reflect the impact of *Mucuna*'s presence or absence in the field.

The monitoring data do, in any case, clearly indicate that *Mucuna*'s impact on maize yield is not dramatic. If negative effects (presumably especially in the first year), or positive effects (presumably particularly in the subsequent years) were strong and consistent, they would have been shown. It comes as no surprise that *Mucuna*'s effects are relatively small. As discussed above, average *Mucuna* biomass, and the associated nutrient content, were relatively low. In addition, in the majority of the fields nutrient losses, especially of N, are largely due to farmers' practice of burning. Moreover, other significant nutrient losses may occur during the dry season--especially in System B, where the lag time prior to the following summer's maize cultivation is long. Finally, the recency of *Mucuna* in the region, and the presence of System A fields (where *Mucuna* primarily benefits winter maize) greatly influence the lack of strong contribution from *Mucuna* to summer maize yields. The lack of such impact is, however, especially regrettable since summer maize is the main maize crop in the region.

CHAPTER 6

ASSESSMENT OF MAIZE-*MUCUNA* SYSTEMS THROUGH ON-FARM EXPERIMENTATION: I. *MUCUNA* BIOMASS AND MAIZE GRAIN YIELD OF FOUR MAIZE-*MUCUNA* SYSTEMS

Introduction

In Chapter 2, we showed that there has been relatively little quantification of *Mucuna* growth in intercropped systems, that studies have mainly focused on sole-cropped, rotational systems, and that there has been little experimentation to assess the performance of *Mucuna* and its main crop under farmer management. To replicate farmer conditions, all management activities, including main crop variety, main crop planting pattern, and fertilizer application, should be modeled after those of the farmer.

On-farm trials targeted to replicate the local performance of *Mucuna* and its main crop can serve two purposes. First, for technology already used on farm, these trials allow the researcher to assess performance of the existing systems. Second, for innovative systems not yet extended to farmers, such trials allow the researcher to realistically assess the potential of *Mucuna* to improve yield in an area before extension efforts are started. The experiments discussed in this and the following chapters pursued both of these general objectives. The specific objectives of maize-*Mucuna* trial discussed in this chapter were to quantify the production of *Mucuna* biomass and the impact of *Mucuna* on maize yield in four different *Mucuna* systems, as compared with maize cultivated without *Mucuna*.

A large part of the impetus behind these on-farm experiments was the observations and experiences of the first summer of agronomic monitoring in 1995. Firstly, the initial monitoring work demonstrated that, due to large within-field variability in management and environmental factors, it would be difficult to gather conclusive evidence through monitoring alone on the impact of *Mucuna* on summer maize yield. Experimental design would lend itself better to the quantification of such an impact. Moreover, both field observations and earlier work in the area (Buckles and Perales, 1995) indicated that additional data were needed on the impact of *Mucuna* on winter maize yield, especially in System A conditions.

Materials and Methods

Guiding Principles of the Trial Design and Management

Because the objective of the field trials was to evaluate the maize-*Mucuna* systems in the region, the trials were designed and managed to mimic existing farmer systems and practices in the study villages. In the case of a new or alternative system, the trials were designed and managed in a way that could realistically be implemented locally, given the available farmer resources. Concretely, the application of this principle meant that:

- Local maize varieties were utilized in the trials;
- Maize was planted in arrangements and densities typical to the study villages;
- Pest control measures were applied following the local practice: i.e., only utilized in extreme cases where the damage could mean a loss of a significant part of the yield;

- Management was designed to be labor saving.

In one important aspect, existing farming systems were not mimicked: No burning of residues was carried out, even though the majority of the maize-*Mucuna* farmers in the region do continue the practice of burning. Burning was omitted from the trials in part to limit the number of treatments, and in part to avoid the complexity of replicating the burning practice, as some farmers burn their fields thoroughly, others in patches and superficially.

During two cycles (winter 1995-96 and summer 1997), the trials were managed by cooperating farmers according to the researcher's instructions. During the other two cycles (summer 1996 and winter 1996-97), the trials were researcher-managed. As with the monitoring, farmer assistance was solicited for the more labor-intensive management and measurements. During all cycles, yield and biomass measurements were carried out in person by the researcher or her assistant.

Treatments

The trial was conducted in three fields in the village of La Candelaria and in one field in the village of Santa Rosa, over four cropping cycles: winters 1995-96 and 1996-97, and summers 1996 and 1997. The trial design was a randomized complete block, with three blocks per field. Plot size was 5 m x 5 m. The treatments consisted of the two maize-*Mucuna* systems practiced by the farmers (Systems A and B), two alternative systems (C and D), and a no-*Mucuna* control system for comparison. Specifically, the treatments were:

- System A: Winter and summer maize with summer *Mucuna*. *Mucuna* was intercropped in summer maize at 40 days after planting (DAP) maize, and slashed just prior to winter maize planting.
- System B: Summer maize with summer-planted *Mucuna*. *Mucuna* was intercropped in summer maize at 40 DAP, and allowed to mature and senesce in the field.
- System C: Winter maize with summer *Mucuna*. *Mucuna* was sole-cropped during the summer season, and slashed prior to winter maize planting. This treatment was included in the trial starting from summer 1996.
- System D: Winter and summer maize with winter and summer *Mucuna*. This system was identical to System A, but with an additional *Mucuna* crop intercropped in winter maize in 1995-96. It was hoped this *Mucuna* would establish during the dry season and generate sufficient biomass prior to the following summer maize planting (Lobo Burle et al., 1992). This system was discontinued as non-viable following the winter 1995-96 season due to poor overwintering of *Mucuna*.
- Control: Winter and summer maize without *Mucuna*. This treatment represented the no-*Mucuna* comparison.

Rainfall During the Four Cropping Cycles

In the first winter cycle (1995-96), maize yield and presumably *Mucuna* growth were greatly reduced by an unusually dry winter. For maize yield, the effect of the drought was presumably worsened by the fact that winter maize planting was delayed by

2 to 3 wk to allow *Mucuna* in systems A and D a longer growing period. Rainfall in January was particularly scanty (39 and 51 mm), well below Catemaco's long term average (93.4 mm; Fig. 3-1). In the summer 1996, rainfall and growing conditions were normal. In the second winter cycle (1996-97), rainfall was unusually high and well-distributed; some foliage stayed green throughout the dry season. Finally, in 1997 summer rains started late, with a consequently late maize planting, and rainfall in July was erratic. The rest of the 1997 summer season was normal.

Trial Set-up

In October 1995, four fields were chosen in which farmers were intercropping *Mucuna* with maize (i.e., *Mucuna* had been planted by the farmers in August 1995). To avoid any carry-over effects of previous years' *Mucuna*, only fields where *Mucuna* had been planted for the first time were chosen. In October 1995, plots were laid out and *Mucuna* plants in the no-*Mucuna* plots (control) were removed with a shovel. The plots were then weeded with a machete, carefully avoiding any damage to the growing *Mucuna*. The summer maize crop was harvested on 17 to 18 Nov. 1995. It was not weighed, as it did not constitute part of the trial.

Trial Management and Measurements in Winter Cycles

In plots of Systems A and D in 1995-96, the *Mucuna* biomass fractions (leaf, stem, and pod), and weed biomass were measured on 17 to 18 Nov. 1995, and in plots of System A on 8 to 9 Nov. 1996 (leaf, stem, pod, mulch, and weed). For this purpose, quadrats covering two maize rows (approximately 2 m by 2 m in 1995) or one maize row (approximately 1 m by 1 m in 1996) were staked out in each plot, using the method described in Chapter 4. Weeds (in control plots) or *Mucuna* and weeds (in Systems A and C plots) were then immediately slashed and plant residues originating from a given plot were kept within that plot. In 1996, some vigorously-growing *Mucuna* had escaped System C plots; only the *Mucuna* growing within such plots was slashed and kept as surface mulch. *Mucuna* biomass measurements were scheduled for System B in January. In 1996, due to the unusually early *Mucuna* senescence, however, adequate measurements could be carried out only in one field at this date. The other three fields were not sampled. In 1997, measurement was conducted at the point of maximum growth on 8 to 15 January.

In Systems A, D, and in control plots, a traditional maize variety was planted with a dibble stick on 20 Nov. 1995 and on 10 to 11 Nov. 1996 at a spacing of 1 m x 1 m, with three seeds per hill (30 000 ha^{-1}). In System B plots, no additional winter management was performed. During the 1995-96 winter cycle, fields were managed by one farmer in each village; the cooperating farmers recorded weekly density counts and observations on maize health, appearance, and incidence of disease and pests. In 1996-97, management was conducted by the researcher's assistant. Fields were manually weeded when needed. In System D plots, *Mucuna* (mixed types white and mottled) was planted on 10 December in alleys between maize rows at a spacing of 1 m x 1 m, with two seeds per hill (20 000 ha^{-1}). In winter 1996-97, maize ear leaves of all plants in four to five hills were cut at tasseling stage, oven dried at 60 to 70°C, and analyzed for N and P. Also in winter 1996-97, maize was harvested as green maize in February to March 1997 to ensure an estimate of maize yield in case of theft.

Winter maize was harvested in the whole plot on 17 to 20 Apr. 1996 or in the nine interior hills in early May 1997 in Systems A and D, as well as in control plots. The number of hills, plants, and cobs were counted. Cobs were divided into healthy, partially damaged, and damaged groups, then counted, shelled, and weighed with hanging scales. Grain weight was measured and humidity taken with a Dickey John HM Grain Moisture Tester. Grain weight per plot was corrected to 15% moisture.

Trial Management and Measurements in Summer Cycles

All experimental plots were slashed with a machete on 8 to 12 June 1996 and on 10 to 15 June 1997. Dry crop residues originating from each plot were kept within the plot. In plots of Systems A, B, and D, summer maize was planted on 18 to 19 June 1996 and early July 1997 (delayed due to late rains) with three seeds per hill. A slightly increased spacing relative to winter maize was employed, by decreasing the distance between rows from 1 m to 0.8 m (37 500 ha^{-1}). In System C plots, *Mucuna* (mixed types white and mottled) was planted at a spacing of 80 cm x 50 cm with two seeds per hill (50 000 plants ha^{-1}). Maize plots were visited regularly, either by the researcher and her assistant (in 1996) or by the farmer cooperators (in 1997). Maize plots were manually weeded as needed through the summer, while *Mucuna* plots (System C) were weeded once, at 30 DAP. At 40 DAP maize, *Mucuna* (mixed types white and mottled) was intercropped in Systems A and B, at maize density, but with two seeds per hill (25 000 ha^{-1}).

At the time of maize tasseling in 1996, measurements of maize height and circumference were performed, and chlorophyll content was determined using a portable chlorophyll meter. Maize ear leaves from four to five hills were cut and oven dried at 60 to 70° C. Maize was doubled in late September 1996 and 1997 (in three fields only), and harvested on 6 to 8 Dec. 1996 and 5 to 10 Nov. 1997 following the procedure presented in Chapter 4.

Laboratory Analysis

Mucuna biomass fractions and maize ear leaves were oven dried and ground in a Wiley Mill to pass a 1-mm stainless steel screen. Nitrogen analysis was conducted by utilizing a modification of the aluminium block digestion technique (Gallaher et al., 1975). Ammonia in the digestate was determined by using semi-automated colorimetry (Hambleton, 1977).

Data Analysis

Data were analyzed mainly using SAS GLM software (SAS Institute, Inc., 1989). The model contained the following terms: field, replication (field), treatment, and field by treatment. Field was tested against replication (field). Preplanned contrasts were utilized mainly to compare treatments; when utilized to compare groups of fields, replication (field) was utilized as the error term. Plotting, correlations, and regression were also utilized.

Results and Discussion

Mucuna Biomass

In all 3 yr of the experiment, system impact on total *Mucuna* biomass production was clear (Table 6-1). System A biomass was one half or less than that of System B, while *Mucuna* grown under System C conditions produced clearly highest biomass. System C biomass in 1997 was lower than in 1996-97, presumably due to the shorter growing period (*Mucuna* planting was delayed due to late rains) and higher weed competition. In the following, biomass fractions will be discussed by cycle.

Biomass fractions in 1995-96

In the winter of 1995-96, *Mucuna* biomass was measured in all fields for Systems A and D only. For System B, biomass was measured only in one field due to unusually early senescence of *Mucuna*. This field was the highest yielding of the four included in the experiment (combined leaf and stem biomass averaged 3990 kg ha^{-1}). For Systems A and D, combined leaf and stem mass was 1120 and 960 kg ha^{-1}, respectively. Because there had been no differences in *Mucuna* management between these systems at that point, no statistical comparison was made (Table 6-1). For these November measurements, amount of leaf-stem biomass was clearly affected by field ($p=0.053$). Weeds averaged 520 kg ha^{-1} in the two systems.

The average intercropped biomasses in Systems A, B, and D are somewhat higher than those obtained by Gilbert (n.d.) who worked in lower rainfall conditions in Malawi. In that study *Mucuna* was planted at 2 WAP maize, average biomass was approximately 3 t ha^{-1}; however, serious competition with maize resulted. If planting was delayed to 6 WAP maize, there was no obvious negative effect of competition on maize, but average biomass was only 1 t ha^{-1}.

Table 6-1. Total *Mucuna* biomass (leaf+stem in 1995-96, leaf+stem+mulch in 1996-97 and 1997) for various maize-*Mucuna* systems in 1995-97. Data are means across four fields in each year.

Maize-*Mucuna* System	1995-96	1996-96	1997
	- - - - - - - - - - - - - - -	kg ha^{-1}	- - - - - - - - - - - - - - - -
System A†	1 120	2 750	4 730
System B‡	3 990#	5 060	§§
System C§	††	7 340	6 160
System D¶	960	‡‡	‡‡
Contrasts and p-values:			
A vs. B		0.005	
A vs. C			0.070
B vs. C		0.004	

† At slashing of summer-intercropped *Mucuna*.
‡ At maturity of summer-intercropped *Mucuna*.
§ At slashing of summer-solecropped *Mucuna*.
¶ At slashing of summer-intercropped *Mucuna*.
# Mean from a single field, not included in system comparisons across fields.
†† No sole *Mucuna* treatment in 1995.
‡‡ Treatment abandoned in second and third years because of poor *Mucuna* establishment.
§§ Experiment in winter ended in November 1997, so data for this treatment were not collected.

Biomass fractions in 1996-97

Results for each of the *Mucuna* and mulch biomass fractions measured during the 1996-97 growing season differed among the three maize-*Mucuna* systems studied (Table 6-2).

Mucuna leaf and stem biomass averaged 2210 kg ha^{-1} in the summer sole-cropped *Mucuna* system. This was more than twice the biomass of the other two maize-*Mucuna* systems (p=0.001 for contrast C vs. B). Similarly, mulch biomass tended to be higher (p=0.189) in System C (5130 kg ha^{-1}) than in System B (4230 kg ha^{-1}). Mulch biomass in System A was lowest at 1790 kg ha^{-1}. Though the proportion of mulch in the total *Mucuna* plus mulch fraction was similar across treatments (64 to 66%; p=0.798), in System B a larger proportion of mulch appeared to be weed and maize residues.

Table 6-2. *Mucuna* biomass in various maize-*Mucuna* systems in 1996-97. Data are means across four fields.

Maize-*Mucuna* System	Leaf	Stem	Mulch	Pod	Weed	Leaf+Stem +Mulch
			kg ha^{-1}			
System A†	460	500	1 790	20	1 240	2 750
System B‡	310	530	4 230	1 400	1 410	5 060
System C§	570	1 640	5 130	390	1 010	7 340
Contrasts and p-values:						
A vs. B	0.034	0.770	0.003	<0.001	0.236	0.005
B vs. C	0.001	<0.001	0.189	<0.001	0.068	0.004

† At slashing of summer-intercropped *Mucuna.*
‡ At maturity of summer-intercropped *Mucuna.*
§ At slashing of summer-solecropped *Mucuna.*

Understandably, pod weight was highest in System B (1400 kg ha^{-1}), where *Mucuna* was allowed to reach maturity. Though absolute weed biomass was only slightly lower in System C than in the other two treatments (p=0.068 for contrast C vs. B), the share of weeds in the total biomass was only 12% due to its higher total biomass. In comparison, the percentage of weeds was 30 and 20% in Systems A and B, respectively. This suggests that in System C, *Mucuna* effectively outcompeted weeds.

Significant field differences were found for all fractions measured. There was significant field-by-system interaction for pod weight only (p= 0.001). Interaction occurred because in one field, pod production tended to be higher in system C plots (680 kg ha^{-1}) than in system B plots (560 kg ha^{-1}).

Such large increases in biomass production of *Mucuna* under sole-cropped vs. intercropped conditions have been obtained in other studies. Gilbert (n.d.) found that sole-cropped *Mucuna* produced 6 t ha^{-1}, three times more than *Mucuna* planted at 2 WAP maize, or six times more than *Mucuna* planted 6 WAP maize. Moreover, Sanginga et al. (1996a) found that *Mucuna* grown in sole-cropped conditions in the derived savanna zone in southern Benin accumulated almost twice as much N as intercropped *Mucuna*.

As discussed in Chapter 4, one should note that the difference in biomass production between the intercropped systems (A and B) and the sole-cropped system (C) in Veracruz can not be considered a result of intercropping alone. Both growing conditions and management appear to cause the large differences observed in biomass among the three systems studied. In Systems A and B, *Mucuna* growth rate is clearly reduced by maize shading from August planting to October maize doubling. In System A, low biomass is also caused by a short growing season due to slashing in November. In System B, low winter rainfall, and early onset of maturity (seemingly due to photoperiod response) both limit growth. In contrast, the greater availability of resources for *Mucuna* in System C (i.e., no light competition, high rainfall) would presumably explain its high accumulation of biomass. In addition, planting densities were higher in System C (modeled after the local bean planting pattern at 50 000 plants ha^{-1}) than in systems A or B (modeled after farmer *Mucuna* planting practice at 20 000 plants ha^{-1}).

Biomass fractions in 1997

In winter 1997, biomass fractions were measured only in early November, and therefore only in Systems A and C (Table 6-3). The combined leaf, stem, and mulch fraction of System C clearly exceeded that of System A (p=0.070). The total *Mucuna* biomass for System C was somewhat lower than the previous year, presumably because *Mucuna* planting was delayed due to late rains and due to suboptimal management in two of the experimental fields. The mulch biomass in System A approximately doubled from the previous year's biomass, presumably due to the fact that the fields had not been burnt for 2 yr. In addition, weediness may have been high at the time of weeding, contributing to the total mulch content.

Table 6-3. *Mucuna* biomass in various maize-*Mucuna* systems in 1997. Data are means across four fields.

Maize-*Mucuna* System	Leaf +Stem	Mulch	Pod	Weed	Leaf+Stem+ Mulch
	- - - - - - - - -	- - - - - - -	- kg ha^{-1} -	- - - - - - - -	- - - - - - - - - - -
System A†	1 060	3 680	10	840	4 730
System C‡	1 900	4 270	260	1 680	6 160
Contrasts and p-values:					
A vs. C	0.006	0.386	<0.001	0.030	0.070

† At slashing of summer-intercropped *Mucuna*.
‡ At slashing of summer-solecropped *Mucuna*.

Nutrient concentration and content of biomass fractions in 1996

Average N concentrations for leaf, stem, pod, and mulch fractions were 4.3, 1.6, 3.1, and 1.7%, respectively, while average P concentrations were 0.25, 0.11, 0.24, and

0.10%, respectively. Weed fraction contained 2.3 and 0.15% of N and P, respectively. System A leaf, stem, and mulch fractions averaged 50 kg N ha^{-1}, while System B's N content was approximately two times greater, and System C content was three times greater (Table 6-4).

Table 6-4. Nitrogen content of the biomass fractions in various maize-*Mucuna* systems in 1997. Data are means across four fields.

Maize-*Mucuna* System	Leaf	Stem	Mulch	Pod	Weed	Leaf+Stem+Mulch
	kg ha^{-1}					
System A†	20	8	22	2	28	50
System B‡	13	8	80	44	28	101
System C§	25	27	95	13	22	147
Contrasts:						
A vs. B	0.035	0.838	0.003	<0.001	0.748	<0.001
B vs. C	<0.001	<0.001	0.326	<0.001	0.162	0.007

† At slashing of summer-intercropped *Mucuna*.
‡ At maturity of summer-intercropped *Mucuna*.
§ At slashing of summer-solecropped *Mucuna*.

Higher nutrient content in the sole-cropped System C was clear in comparison to the intercropped systems A and B ($p<0.001$). Of the two systems with long *Mucuna* growing seasons (B and C), higher N content in sole-cropped *Mucuna* conditions (System C) was equally clear ($p=0.007$). In comparison to N content of cover legumes reported in literature, System A's content is clearly below the average N accumulation of 100 kg ha^{-1} (Peoples and Craswell, 1992). In comparison to literature available, *Mucuna*'s N content in System B is considered average, while that of System C is relatively high. In both systems, N content is clearly below those measured in two other studies in on-farm conditions: Sanginga et al. (1996a), measured an average of 166 kg ha^{-1} in farmer-managed maize-*Mucuna* fields, while average N content in Triomphe's Honduras study was 284 kg ha^{-1}. Nitrogen content in the weed fraction was relatively high (28, 28, 22 kg in Systems A, B, and C respectively), while pod N content was 2, 44, and 13 kg ha^{-1} in Systems A, B and C, respectively. Findings regarding P content largely mirrored those for N (Table 6-5).

Table 6-5. Phosphorus content of the biomass fractions in various maize-*Mucuna* systems in 1997. Data are means across four fields.

Maize-*Mucuna* System	Leaf	Stem	Mulch	Pod	Weed	Leaf+Stem +Mulch
	kg ha^{-1}					
System A†	1.1	0.6	1.7	0.04	1.8	3.4
System B‡	0.8	0.5	4.3	3.4	1.8	5.5
System C§	1.8	1.8	5.8	1.0	1.3	9.4
Contrasts and p-values:						
A vs. B	0.358	0.416	0.026	<0.001	0.878	<0.001
B vs. C	0.012	<0.001	0.138	<0.001	0.067	0.001

† At slashing of summer-intercropped *Mucuna*.
‡ At maturity of summer-intercropped *Mucuna*.
§ At slashing of summer-solecropped *Mucuna*.

Maize Yield

The maize-*Mucuna* systems impacted maize yield during the winter cycles; no significant effects were found during the summer cycles (Table 6-6). No significant system-by-cycle interaction was found for maize yield (p=0.253). However, such analysis was conducted only for maize-*Mucuna* System A and the control which were common to the four cycles studied. In addition, there were large yield differences among cycles due to environmental conditions. For these reasons, results of the three different cycles will be discussed separately.

Mucuna's beneficial impact on winter maize yield

As has been reported to be the case in Atlantic Honduras (Buckles et al., 1996), *Mucuna* impacted winter maize yield positively from the first cycle onwards.

Maize yield in winter 1995-96: In the first winter cycle, *Mucuna*'s impact on maize yield was high in relative terms (Table 6-6). System A, where summer maize-*Mucuna* was followed by winter maize, yielded 55% more than the no-*Mucuna* system (p=0.005). Intercropping a second *Mucuna* crop in winter maize (System D) did not affect maize yield (p=0.603). There was no effect of field on maize yield (p=0.225).

In comparative terms, such winter maize yield increase is quite high, considering the relatively low *Mucuna* biomass prior to winter maize planting (combined leaf and stem fractions averaged 1100 kg ha^{-1} across fields). As winter maize was planted within no more than 2 d of *Mucuna* slashing, the mulch nutrient release was presumably well-synchronized with maize nutrient needs. *Mucuna* mulch on the soil surface may have also conserved soil moisture during this unusually dry winter.

In absolute terms the added yield benefit in System A was, however, only 150 kg ha^{-1} in comparison to the no-*Mucuna* system due to very low winter maize yields. Importantly, such small yield increase in absolute terms may not be sufficient to offset the labor costs of planting *Mucuna*.

Maize yield in winter 1996-97: In the winter of 1996-97, similarly large comparative yield increases were found in the system where August-intercropped

Mucuna was slashed just prior to winter maize planting (System A). Across fields, yield increased 45% from the no-*Mucuna* system (740 kg ha^{-1} vs. 510 kg ha^{-1}, respectively; p=0.036). As discussed in the earlier section, the average N content of System A *Mucuna* biomass at slashing was only 50 kg ha^{-1}; despite this, yield increases were clear and substantial. System C, in which winter maize followed summer-season, sole-cropped *Mucuna*, yielded 1110 kg ha^{-1} of maize; this represented an average of 118% more than the no-*Mucuna* control, but only 49% more than maize-*Mucuna* System A (p=0.002). As in the previous winter cycle, there were no differences among fields in maize yield (p=0.584).

The relatively high yield increase from System A attests to the importance of synchronizing nutrient release from the GMCC and nutrient uptake by the main crop. Costa et al. (1990) found that *Mucuna aterrima* leaves placed on the soil surface increase soil N rapidly during the first 25 d. In this study, winter maize was planted within 2 d of *Mucuna* slashing. Even assuming a generous N recovery of 80% (van Noordwijk et al., 1995), added N available from *Mucuna* to winter maize was no more than 40 kg ha^{-1}. Relatively large yield increases have been obtained in other studies when *Mucuna* slashing was rapidly followed by maize planting. Gordón et al. (1993) found that approximately 2 t ha^{-1} of *Mucuna* biomass increased maize yield from 2.2 to 3.1 t ha^{-1}. Winter maize yield increase in System C conditions was very high, as Gordón et al. (1997) found that adding 211 kg ha^{-1} of N in *Mucuna* increased maize yield from 2.5 to 4.1 t ha^{-1}.

Table 6-6. Maize yield in various maize-*Mucuna* systems. Data are means across four fields.

Maize-*Mucuna* System	Winter 1995-96	Summer 1996	Winter 1996-97	Summer 1997
	--------------- ----- kg ha^{-1} ----------------- - -			
System A†	410	1 000	740	940
System B‡	None#	1 090	None#	1 000
System C§	††	None#	1 110	None#
System D¶	380	‡‡	‡‡	‡‡
Control	260	960	510	810
Contrasts and p-values:				
A vs. Control	0.005	0.752	0.036	0.731
B vs. Control	-	0.312	-	0.321
A vs. D	0.603	-	-	-
A vs. C		-	0.002	-
A vs. B	-	-	-	-

† Summer+winter maize; *Mucuna* intercropped in summer.
‡ Summer maize; *Mucuna* intercropped in summer.
§ Winter maize; sole *Mucuna* in summer.
¶ Summer+winter maize; *Mucuna* intercropped in summer and winter.
# Maize not produced during this season.
†† Treatment included in second year only.
‡‡ Treatment abandoned after first winter maize harvest.

Impact of *Mucuna* on maize yield components and nutrient concentration: In the winter of 1995-96, the only yield component that was affected by system was ear grain weight (p=0.007, Table 6-7). In comparison to the no-*Mucuna* control, positive impacts from *Mucuna* in System A approached significance for total ear number (0.123) and for number of ears per plant (p=0.125). Though average ear grain weight was low in all systems due to unfavorable winter conditions, it was clearly lower in the no-*Mucuna* control (at 25 g) than in the maize-*Mucuna* systems A and D (34 and 33 g respectively, p=0.003).

Table 6-7. Maize yield components in various maize-*Mucuna* systems during winter cycles 1995-96 and 1996-97. Data are means across four fields.

	Winter 1995-96		Winter 1996-97		
Yield component	Control	System A†	Control	System A†	System C‡
Plants ha^{-1}	24 000	24 530	21 020	20 090	25 930
Ears plant^{-1}	40	47	61	64	77
Ears ha^{-1}	9 630	11 570	12 590	13 430	19 190
Grain g cob^{-1}	25	34	38	49	53
Contrasts and p-values:	Control vs. A		Control vs. A		A vs. C
Plants ha^{-1}	0.861		0.700		0.003
Ears plant^{-1}	0.125		0.482		0.015
Ears ha^{-1}	0.123		0.565		<0.001
Grain (g cob^{-1})	0.007		0.006		0.530

† Summer+winter maize; *Mucuna* intercropped in summer.

‡ Winter maize; sole *Mucuna* in summer.

In 1996, system affected several yield components and ear leaf N concentration. Between System A and the no-*Mucuna* control only average ear grain weight differed, and it was 11 g higher in System A (p=0.006). Differences between System C and System A occurred in all yield components except for average grain weight. In System C plots, a larger number of maize plants survived (p=0.003), and produced more ears, both per plant (p=0.015) and as total number (p<0.001). The low average grain weight in all systems even in this relatively favorable year attests to the generally unfavorable conditions of winter maize production. Maize ear leaf N concentration was only slightly higher in the maize-*Mucuna* System C than in the no-*Mucuna* comparison (p=0.086); for

P no difference was found (Table 6-8). The average nutrient concentrations were very low, as critical values for N and P concentration at tasseling are approximately 3% and 0.25%, respectively (Jones et al., 1990). Such low values attest to the unfavorable winter growing conditions and poor fertility of the fields in this trial. In the Atlantic Honduras study of Triomphe (Triomphe, 1996; Buckles et al., 1998), maize ear leaf N concentration was considerably higher (2.81 and 2.41% in 1993 and 1994, respectively).

Table 6-8. Winter maize ear leaf nutrient concentration at tasseling in various maize-*Mucuna* systems. Data are means across four fields.

Maize-*Mucuna* System	N (%)	P (%)
	--------------- %	---------------
System A†	1.9	0.17
System C‡	2.0	0.18
Control	1.9	0.17
Contrasts and p-values:		
C vs. Control	0.086	0.430

† Summer+winter maize; *Mucuna* intercropped in summer.
‡ Winter maize; sole *Mucuna* in summer.

In both 1995 and 1996, lower pest and disease incidence were also associated with *Mucuna* systems. In 1995, 59% of the cobs were partially damaged in the no-*Mucuna* control, while in *Mucuna* Systems A and D, only 49% (p=0.020) were damaged. In 1996, 84% of the ears in the no-*Mucuna* plots were partially damaged in comparison to 63 and 76% in Systems A and C (p=0.031).

In conclusion, the higher winter maize yield in the maize-*Mucuna* systems was associated both years with more beneficial conditions during the grain-filling period (presumably caused by the moisture conservation of mulch and/or higher mineralization of N), with consequent increases in ear grain weight. Impacts at the level of plant number and ear number were evident only with System C during the wetter winter cycle, with its associated higher maize production. As evidenced by the lower number of damaged cobs, plant health was better in the maize-*Mucuna* system, which may partially explain the higher ear grain yield.

Mucuna's lack of impact on summer maize yield

In contrast to the two winter maize cycles, there were no differences in summer maize yield among any of the maize systems studied.

Maize yield in summer 1996: In 1996, the no-*Mucuna* control yielded 960 kg ha^{-1} while the maize-*Mucuna* System A yielded 1000 kg ha^{-1} (p=0.752, Table 6-6). System B, with no previous winter maize, yielded 1090 kg ha^{-1} (p=0.312 for contrast System B vs. the control). The absence of response to *Mucuna* was consistent across fields (field by system interaction p=0.225), and there were no yield differences among fields (p=0.876). It should be noted that biomass production in some fields may have been low, as during the previous winter *Mucuna* senesced early due to low rainfall. Relatively high biomass (approximately 4.0 t ha^{-1}, including pod) was, however, measured in the highest-yielding field without resulting benefits. Other studies have reported benefits of *Mucuna* even in systems where *Mucuna* is left as surface mulch for a long time before the main crop planting (Ile et al, 1996).

Maize yield in summer 1997: In 1997, the no-*Mucuna* treatment yielded 810 kg ha^{-1}, while maize-*Mucuna* System A yielded 940 kg ha^{-1}, and System B produced 1000 kg ha^{-1}. No impact of the system was detected with pre-planned contrasts, and there was no interaction between system and field. As discussed above, *Mucuna*'s leaf, stem, and mulch N content in System B in the previous year was twice that of System A (averaging 101 kg ha^{-1}). Despite such high N content, no clear impacts were determined. Chapter 5 explored possible factors impacting lack of strong impact of *Mucuna* on summer maize in the monitoring fields. It should be noted that even in a situation where successful treatment structure was employed (no mixing of Systems B and C), where the design problems of the monitoring were absent, and where no burning was practiced, impact of winter or summer *Mucuna* on summer maize could *not* be detected. Perhaps the most likely explanations are: (1) the long time lag and consequent losses of nutrients, and (2) the lack of synchronization between the nutrient release of *Mucuna* and the nutrient need of the summer maize.

Annual maize productivity in the four maize systems

The annual maize productivity of the four maize systems studied was determined for 2 yr: first, for the combined winter 1995-96 and summer 1996 period, and second, for the combined winter 1995-96 and summer 1997 period (Table 6-9). This was done to provide an overall assessment of maize productivity.

During the first annual cycle, only Systems A, B, and the control were included in the analysis because System D was discontinued after the first winter maize cycle. There was a trend toward increased annual productivity from the inclusion of *Mucuna* in the double-cropped maize system (System A vs. control, $p=0.202$). The short-term yield benefits from any double-cropping are therefore obvious, as allowing *Mucuna* fallow over the winter period (System B) clearly does not permit recovery of the lost winter maize yield, even in a year when winter yield was very low.

For the second annual cycle (winter 1996-97 + summer 1997), Systems A, B, C, and control were included in the comparison. Of the two double-cropped cycles, the maize yield in System A exceeded maize yield in the no-*Mucuna* control by 360 kg ha^{-1} (p=0.015). However, annual production of the no-*Mucuna* control (1320 kg ha^{-1}) exceeded maize productivity in System B by 320 kg ha^{-1} (p=0.001).

Table 6-9. Annual maize productivity in various maize-*Mucuna* systems. Data are means across four fields.

Maize-*Mucuna* System	Winter 1995-96 + Summer 1996	Winter 1996-97 + Summer 1997
	kg ha^{-1}	
System A†	1 410	1 680
System B‡	1 090	1 000
System C§	-	1 110
Control	1 220	1 320
Contrasts and p-values:		
A vs. Control	0.202	0.015
B vs. Control	0.332	0.001
A+Control vs. B+C		<0.001
A+B+C vs. Control		0.194

† Summer+winter maize; *Mucuna* intercropped in summer.

‡ Summer maize; *Mucuna* intercropped in summer.

§ Winter maize; sole *Mucuna* in summer.

¶ No System C treatment in W 1995-96.

Summary and Conclusions

Estimations of the annual productivity of the four systems studied clearly affirm the short-term benefits from double cropping of summer and winter maize in the study area, however unsustainable this practice may be in the long term. The increases in total annual maize yield gained through double-cropping (in this study, evaluated for *Mucuna* systems only through Systems A vs. B and C) were on average greater than the corresponding yield increases from the inclusion of *Mucuna*. This was the case across the cropping systems, and even in a year when winter maize yield was low due to inclement weather. In most cases, absolute yield advantages from either the inclusion of *Mucuna* or from double-cropping are low, amounting to a few hundred kg ha^{-1}. However, given the low level of maize production in the area such yield differences are quite high in relative terms. Moreover, given the widespread regional poverty, such increases in food production or in annual income can be significant for the welfare of rural families.

Maize Double-Cropping Systems (Systems A, D, and no-*Mucuna* Control)

The short-term productivity of such double-cropping systems clearly and understandably exceeds that of the systems with a single production cycle. Longer-term productivity of such double-cropping systems is questionable, even in the presence of *Mucuna*.

In System A, August-intercropped *Mucuna* was slashed prior to winter maize planting. Although *Mucuna* biomass under System A conditions was relatively low (averaging 2.8 t ha^{-1}, and 50 kg ha^{-1} of N), the summer's *Mucuna* intercrop did allow winter maize yields to increase up to 50%. No residual effect was detected on the subsequent summer maize yield; however, System A's summer yield tended to exceed that of no-*Mucuna* control. Such small to non-existent residual effects is consistent with reports in literature that 80% of the added N from *Mucuna* is released during the first catch crop (van Noordwijk et al., 1995). Annual maize production increases in System A were small but significant in comparison to the no-*Mucuna* control. It should be noted that the long-term sustainability of System A is doubtful, given double-cropping and the relatively low *Mucuna* productivity (averaging 2.8 t ha^{-1}, and 50 kg ha^{-1} of N).

System D was included in trials only for one cycle, and consisted of summer and winter maize, both intercropped with *Mucuna*. It was hoped that *Mucuna* planted in December would establish during the winter season, and eventually generate significant biomass to benefit summer maize. Two problems were encountered with the December planting date. First, most of the *Mucuna* plants did not overwinter during the unusually dry 1995-96 winter. Second, in one field *Mucuna* completed its reproductive cycle prematurely (in April), despite very stunted growth; the few plants that produced pods averaged a height of approximately 20 cm. Duke (1981) classifies *Mucuna* as a short-day plant, while Keatinge et al. (1996) reports that flowering is induced by cold nights. Trials in the region continue to assess the overwintering of *Mucuna* planted at various winter dates (Balente Herrera, personal communication). If *Mucuna* could overwinter successfully during all or most years, it would remain to be seen whether farmers would be willing to delay summer maize planting so that *Mucuna* could generate sufficient biomass prior to slashing.

Attesting to the yield advantage derived from double-cropping, total annual maize production of the no-*Mucuna* control was second highest of the five systems tried.

However, maize yield in each cycle was lowest in this system. Field observations lend support to the unsustainability of the intensive double-cropping in the region without added nutrients. It would appear that the lower relative yield in the control plots in the second year of the maize system trial may already signify such trends, as may the large, 158% yield increase from System A in one of the experimental fields (Field 1). Field observations suggest that in the low-fertility fields, winter maize production is virtually nil in average years.

Summer Maize With Summer-Planted *Mucuna* (System B)

The most commonly adopted maize-*Mucuna* system, where *Mucuna* is intercropped in summer maize and allowed to mature in the field, was not found to increase summer maize yield during its first 2 yr. The summer yield in System B plots did tend to be the highest, however. Such yield advantage may be expected to increase in later years, presumably in part due to winter fallowing, in part due to *Mucuna*'s effects. In this study, total annual production remained limited in System B, a consequence of the absence of maize production in the winter season.

It could be considered quite surprising that in the 2 yr of this trial there was no clear response of summer maize to *Mucuna* in System B. The absence of clear summer maize yield response could be caused by several factors. First, the *Mucuna* biomass was relatively low, especially during the first year, resulting from early senescence and the climatological factors. However, in the second year *Mucuna* produced a biomass with higher than average contribution of nutrients in green manures (Peoples and Craswell, 1992). Second, and more importantly, there was a lengthy time lag prior to planting the summer maize, which has been associated with nutrient losses through different avenues (Lobo Burle et al., 1992; Lathwell 1990; Carsky et al., 1998).

The lack of summer maize response raises concerns over the production potential of System B, especially since no response was detected in any of the four fields studied. Though such intercropped maize-*Mucuna* systems have increasingly been the focus of promotional efforts (Buckles and Barreto, 1996), their impacts on main crop have been relatively little studied. Studies and reports from Benin (where the maize-*Mucuna* system is similar) indicate high benefits (Vissoh et al., 1998; IITA, 1993). However, in Benin part of the yield impact is seemingly derived from *Mucuna*'s ability to suppress *Imperata*, a common weed in the area. Without such dramatic weed control impacts, *Mucuna*'s ability to increase main crop yields may be limited, especially during the first 2 yr of utilization. Of note, the trial covered only the two first 2 yr of *Mucuna* intercropping, and does not necessarily indicate that there will be no long-term trends. In any case, the lack of clear maize yield increase during its first years of use may undermine the adoption potential of this system.

System With Winter Maize Only (System C)

The greatest *Mucuna* biomass production, averaging 7.3 and 6.2 t ha^{-1} of dry matter that contained approximately 150 kg ha^{-1} of N, was obtained in the rotational System C where *Mucuna* is sole-cropped during the summer season, and winter maize is planted after *Mucuna* slashing. Subsequent impacts on winter maize production are also highest under this system, averaging over 50%. Several other studies have attested to *Mucuna*'s consistently good performance in sole-cropped conditions, and the associated large yield increases in subsequent main crops from the rotational inclusion of *Mucuna* in the cropping system (Lathwell, 1990; Gordón et al., 1993; Cahn et al., 1993).

The relatively high yield impact from System C might attract farmers to adopt this system. Moreover, the soil conservation benefits from such a system are presumably higher, due to the greater *Mucuna* biomass as well as the more effective ground cover during the period with heaviest and most intense rains.

There are several issues that negatively affect System C's adoption potential. Most importantly, the winter cycle is traditionally a minor maize cropping cycle in the area due to its low rainfall and often high winds. Consequently, winter maize production is traditionally felt to be a high-risk, low yield proposition. It should be noted that labor inputs in winter maize production are also lower due to less weed pressure and easier land preparation. The continued presence of *Mucuna* as a cover crop can likely alleviate some of the specific constraints of the winter maize cycle by improving the soil water status; improved maize nutrition may also increase development rate and allow some drought avoidance. Yet even the 50% or higher yield increases during the winter period may not be enough in absolute terms to offset the loss of summer season maize if there is no added incentive to establish *Mucuna* fallow over the summer season.

In conclusion, no beneficial impacts on summer maize production were found in maize-*Mucuna* systems A and B during the first two years of *Mucuna*'s inclusion in the cropping system. In contrast, winter maize yields did increase during both years of the study. Though such yield increases were higher in System C, where winter maize was preceded by summer sole-cropped *Mucuna*, winter maize yield was also significantly increased by the relatively low *Mucuna* biomass and nutrient content of System A.

CHAPTER 7

ASSESSMENT OF MAIZE-*MUCUNA* SYSTEMS THROUGH ON-FARM EXPERIMENTATION: II. *MUCUNA* VARIETY EVALUATION AND IMPACT ON SUBSEQUENT WINTER MAIZE PERFORMANCE

Introduction

Mucuna's taxonomy has not been well delineated, and no in-depth studies on the taxonomy of the available varieties have been conducted (Lorenzetti et al., 1998). In the literature, *Mucuna* varieties are often distinguished by place of origin and/or by seed color. Recent evidence on the variability of L-dopa content in *Mucuna* seeds of white, mottled, and black color suggests that genetic variation does exist between types differentiated by seed color (Lorenzetti et al., 1998).

In the five study villages, farmers most typically utilize *Mucuna* with either white or mottled seed. Often they are planted mixed, while some *Mucuna* with black seed color is also available. White and mottled *Mucuna* types are indistinguishable in the field; however, the black type is differentiated somewhat by its more slender leaves and purple inflorescence. Farmers in the study villages reported contradictory impressions on the comparative performance of these three *Mucuna* types. No quantification of biomass production had been conducted in the area, nor was any characterization of *Mucuna* varieties available. At IITA, in Nigeria, the impact of fertilization on *Mucuna* types with different seed color has recently been studied (Tian and Kang, 1998; Tian et al., 1998). Because of the absence of data on possible impacts of *Mucuna* variety on biomass production, a field experiment was designed to compare the biomass production of these three *Mucuna* types. *Mucuna* types were cultivated as sole crops during the summer season in order to generate additional information on the potential production of *Mucuna* grown in System C conditions (summer sole-cropped *Mucuna* followed by slashing and winter maize).

An additional objective of this experiment was to further examine the potential of System C to increase winter maize yield. As discussed in Chapter 3, winter maize yield in the study region is low. In the literature, average winter maize yield has been reported at 500 kg ha^{-1} (Buckles and Erenstein, 1996), but it is common to see fields with maize yield of 200 to 300 kg ha^{-1}. Typically, low and erratic rainfall and high winds are named as causes for the low yields.

Experimental data reviewed in Chapter 2 support the potential of higher main crop yield in a rotational system where the green manure/cover crop (GMCC) is slashed and the main crop is planted immediately. Much of the spontaneous adoption of *Mucuna* as a GMCC has used this system, notably in the Atlantic Honduras (Triomphe, 1996), but also in the Mecayapan area of the Sierra de Santa Marta region of Veracruz (Buckles and Perales, 1995).

In this study, the first year of monitoring suggested that the current farmer-practiced systems exerted relatively little beneficial effect on summer maize production. Low and variable *Mucuna* biomass, the relatively long time lag from *Mucuna* senescence to summer maize planting, and the local custom of residue burning prior to summer all seemed to contribute to the lack of significant, observable impacts. In contrast, it was expected that during the summer *Mucuna* could generate a relatively large amount of biomass in sole-cropped conditions with high nutrient content and large mulch layer. It was further hypothesized that a system that benefits winter maize only may be more readily adopted, since fields where winter maize is planted are typically not burnt.

The experiments in this chapter focus on biomass production of the three *Mucuna* varieties under System C conditions, and their subsequent impacts on winter maize yield. These experiments contribute to several of the general objectives of this study. First, by quantifying the biomass production of the three varieties, the *Mucuna* variety trial explores the impact of one key management factor (choice of variety) affecting the productivity of *Mucuna* in the farmer-managed systems. Second, by examining *Mucuna* biomass production and its consequent impacts on winter maize yield under System C conditions, the two trials contribute towards the assessment of alternative maize-*Mucuna* systems.

The two experiments discussed in this chapter were conducted in the same fields, though biomass production was evaluated in a larger number of fields than the maize yield impact. The biomass production and maize yield aspects are discussed in the following as separate trials.

Materials and Methods

Mucuna Variety Trial

The trial was conducted during two summer cycles. In the summer of 1996, the trial was conducted in 11 fields located in five villages: Santa Rosa (three fields), La Candelaria (three fields), Salto de Eyipantla (two fields), Soteapan (one field), and San

Fernando (two fields).[11] In 1997, the trial was conducted only in La Candelaria (three fields) and in Santa Rosa (two fields).

The trial compared the three *Mucuna* types, differentiated by their seed color, that are available in the region: white, mottled, and black. The *Mucuna* types were grown in System C conditions, i.e., sole-cropped during the summer season. The trial design was a randomized complete block, with two blocks per field. Plot size was 5 m x 5 m.

In early June 1996, four plots were laid out per block, and dried plant residues were slashed with a machete and removed from the plots. The three *Mucuna* types were planted 13 to 25 June 1996 and in early July 1997 (delayed due to late rains) at a spacing of 80 cm x 50 cm with two seeds per hill (50 000 ha^{-1}). In the fourth plot, maize was planted at traditional density either by the farmer or by the researcher. *Mucuna* was weeded at 1 mo after planting, and seedling density counted. At 2 mo after planting, percent ground cover was estimated and *Mucuna* plant height measured (in 1996 only). On 20 to 26 Oct. 1996 and 5 to 10 Nov. 1997 *Mucuna* and weed biomass were measured from a representative 1 m x 1 m quadrat (for detailed description of the method, see Chapter 4).

Winter Maize Trial

The winter maize trial took place during winter 1996-97 only. It was conducted in seven of the 11 *Mucuna* variety trial fields in Santa Rosa, La Candelaria, and Soteapan. From 27 to 29 Oct. 1996, *Mucuna* and maize plots were slashed. Plant residues (*Mucuna*, weeds, and mulch) originating from each plot were kept within the plot. *Mucuna* that had grown outside of the experimental area, or into the maize plot was removed. Winter maize was planted 5 to 8 November at 30 000 plants ha^{-1} (three seeds per hill). Maize was weeded manually as needed. Ear leaves of all maize plants in four to five hills were cut at tasseling, oven dried at 60 to 70°C, and analyzed for N and P. To insure yield estimates in the case of theft, maize was harvested from border rows as green maize in February to March 1997. Grain was harvested from the interior nine hills of each plot between 15 April and 8 May following the procedure described in Chapter 4.

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[11] Additional trials, planted by cooperating farmers in five additional villages were discontinued due to problems in their setup.

Laboratory Analysis

Mucuna biomass fractions and maize ear leaves were oven dried and ground in a Wiley Mill to pass a 1-mm stainless steel screen. Nitrogen analysis was conducted by utilizing a modification of the aluminium block digestion technique (Gallaher et al., 1975). Ammonia in the digestate was determined by using semi-automated colorimetry (Hambleton, 1977).

Data Analysis

Data were analyzed mainly using SAS GLM (SAS Institute, Inc., 1989). The model contained the following terms: field, replication (field), treatment, and field by treatment. Field was tested against replication (field). Preplanned contrasts were utilized to compare treatments. Correlations and regression analysis were also utilized.

Results and Discussion

Mucuna Variety Trial

Mucuna grew quickly under sole-cropped conditions during summer. As much of the crop residues had been cleared prior to *Mucuna* planting, a clear majority of the mulch layer, typically 80-90%, was of *Mucuna* origin. By 2 mo after planting, *Mucuna* had already produced almost 100% ground cover in the fastest growing fields, and had begun shedding leaves in these sole-cropped conditions, presumably due to light competition. Such shedding intensified greatly with the advancing season, forming a relatively uniform mulch layer in most fields by slashing time.

Biomass fractions in 1996

In the plots with highest biomass, *Mucuna* produced up to almost 5 t ha^{-1} of live matter, and 11 t ha^{-1} of total matter during its 4-mo growing period. In these highest-producing fields, biomass production was comparable to average *Mucuna* biomass measured by Triomphe in Atlantic Honduras, where *Mucuna* has been cultivated for decades (Triomphe, 1996) and is comparable to the highest *Mucuna* biomasses obtained under experimental conditions (Lathwell, 1990; Derpsch and Florentin, 1992; Cahn et al., 1993). Only the pod weights remained very low (40-110 kg ha^{-1}) as the *Mucuna* was measured and slashed at an early flowering stage.

There were no differences in *Mucuna* biomass between white and mottled types, but the black variety had lower leaf ($p=0.014$), stem ($p=0.011$), and pod ($p= 0.038$) biomasses than did the white and mottled varieties (Table 7-1). Moreover, mulch fraction was lower in the black variety plots than the others ($p=0.068$). Combined leaf, stem, pod, and mulch weight for white and black differed by 1050 kg ha^{-1} (p=0.022). Weeds averaged a mere 10%, approximately, of the total biomass; in five fields, live weeds constituted less than 5% of the total biomass. Clearly, *Mucuna* outcompeted weeds effectively in most of the fields with a single weeding performed 1 mo after *Mucuna* planting. Similarly, weed biomass measured by Triomphe (1996) in Atlantic Honduras was very small.

Table 7-1. Biomass of three *Mucuna* varieties. Data are means across 11 fields in 1996.

Variety	Leaf	Stem	Mulch	Pod	Weed	Leaf+ Stem+Pod +Mulch
	------------ ------ kg ha^{-1}					----------------
White	1 080	2 430	4 280	110	590	7 900
Mottled	1 000	2 250	4 630	70	750	7 940
Black	890	1 950	3 970	40	900	6 850
Contrasts and p-values:						
W+M vs. B	0.014	0.011	0.068	0.038	0.191	0.022
W vs. M	0.197	0.294	0.276	0.179	0.421	0.931

The lower field germination of the black variety (approximately 62% as compared to 84% for the others) at least partially explains its lower biomass. In addition, field observations suggest that the morphology of the black variety, with its thinner stems and seemingly lower leaf weight, may have accounted for some of the difference.

The black *Mucuna* type clearly exhibited a slower initial development, as reflected by differences in percentage ground cover among the treatments at 2 mo (74, 78, and 53% for white, mottled, and black, respectively). Poorer field germination of the black variety, resulting in lower density partially caused this poorer ground cover. However, less difference in development stage was seen at slashing. The lower pod weight of the black type at the biomass measurement stage (p=0.038 for contrast with other two types) may suggest slower development, but no firm conclusions can be made due to its lower density and the early stage of growth at slashing. The ratio of leaf weight to stem weight could provide an estimate of *Mucuna*'s maturity, as the more mature plants shed leaves while stem weight stays nearly equal. However, the ratio's utility is questionable, as environmental conditions most likely play a role equally strong to that of maturity. No significant difference was found in leaf/stem ratio comparing white plus mottled varieties with black (p=0.881).

Field effects were significant for all fractions measured, and differences among fields were great (p=0.001, <0.001, <0.001, 0.001, and 0.015, respectively for leaf, stem, pod, weed, and mulch fraction). However, *Mucuna* types performed uniformly across fields (field by treatment interaction p=0.549, 0.179, 0.407, 0.585, and 0.750, respectively for leaf, stem, pod, weed, and mulch fraction). In the literature, *Mucuna* has been reported to grow well in poor-fertility soils, given enough rainfall (Soil Fertility Network, n.d.). However, as would be expected, its biomass production is higher in higher-fertility soil (Tian and Kang, 1998; Tian et al., 1998). This study confirms both of these reports. In some of the low-yielding fields of this study, poor soil fertility conditions seemingly prevailed, as suggested, for example, by the poor growth of summer maize in areas adjacent to the experimental plots (estimated maize yields 500 to 800 kg ha^{-1}). Despite this, *Mucuna* biomass production was almost 5 t ha^{-1}. However, the biomass production was twice that in the fields with better fertility. Live *Mucuna* biomass (leaf, stem, and pod) ranged between 1840 and 4890 kg ha^{-1} in the 11 fields. A large part of the *Mucuna* biomass consisted of mulch, with field averages for mulch ranging from 3970 to 4280 kg ha^{-1}.

Comparison of fields located in different villages confirmed the observation during the monitoring that fields in Salto de E. tended to produce higher biomass; however, no firm conclusions can be made on the basis of just the two fields from Salto de E. included in this experiment. Biomass production in flat fields clearly exceeded that in sloped fields (p=0.004 for combined leaf, stem, pod, and mulch fraction), attesting to the fact that more beneficial maize production environments clearly favor *Mucuna* production as well. As a consequence, field-level correlation between the combined *Mucuna*-mulch biomass in this trial and the following winter's maize yield (recorded in the no-*Mucuna* treatment in the Winter Maize Trial) was 0.85 (p=0.032). Such correlation is very high, given the fact that production of the crops took place over different seasons (*Mucuna* in the summer; maize in the winter).

Nutrient content in 1996

The combined leaf, stem, and mulch fraction averaged approximately 170 kg ha^{-1} of N in the white and mottled *Mucuna* types (Table 7-2). The N content of the black *Mucuna* type was about 20 kg less (p=0.034). These average contents are similar to other trials with high biomass production (Lathwell, 1990; Cahn et al., 1993), but well below the average N content of 313 kg ha^{-1} (at 12 WAP) reported from the farmer-managed fields in southern Benin. These same biomass fractions contained approximately 6 kg ha^{-1} of P; the black *Mucuna* type's P content was slightly less than that of white and mottled types (p=0.029, Table 7-3). The N content of the weed fraction tended to be greatest for black plots because of a trend to higher weed yield.

Table 7-2. Nitrogen content in the biomass fractions of three *Mucuna* varieties. Data are means across 11 fields in 1996.

Variety	Leaf	Stem	Mulch	Pod	Weed	Leaf+Stem+ Mulch
	----------------		kg ha^{-1}	----------------		
White	51	41	80	4.3	12	172
Mottled	46	36	87	2.4	16	169
Black	42	31	75	1.5	18	148
Contrasts and p-values:						
W+M vs. B	0.024	0.005	0.267	0.030	0.146	0.034
W vs. M	0.085	0.125	0.424	0.045	0.198	0.810

Table 7-3. Phosphorus content in the biomass fractions of three *Mucuna* varieties. Data are means across 11 fields in 1996.

Variety	Leaf	Stem	Mulch	Pod	Weed	Leaf+ Stem+ Mulch
	----------------			kg ha^{-1}	----------------	
White	2.6	3.9	4.6	0.3	1.0	6.6
Mottled	2.5	3.7	5.0	0.2	1.4	6.2
Black	2.5	3.0	4.0	0.1	1.6	5.5
Contrasts and p-values:						
W+M vs. B	0.510	0.018	0.061	0.028	0.118	0.029
W vs. M	0.486	0.528	0.358	0.047	0.237	0.418

Biomass fractions in 1997

The trial was conducted only in five fields in 1997. The average biomass production was about 1 t lower than in 1996. Such difference was largely caused by the later planting date, omission of some of the higher-yielding fields of 1996, and higher weed competition in some fields. The combined *Mucuna*-mulch biomass averaged 6670, 6800, and 4900 kg ha^{-1} for the white, mottled, and black varieties, respectively; this total fraction was lower for the black variety (p=0.005; Table 7-4). As in 1996, no differences were found in any individual fractions between the white and mottled *Mucuna* types, while the black variety produced less pod (<0.001) and mulch (p=0.009). Lower mulch biomass for the black variety is, again, presumably related to at least two factors: lower biomass production during the previous year, and slower development (and consequently less shedding) during the study year. The lower pod production of the black variety is marked, and lends more evidence to the slower development of the black variety. There was no difference in the combined leaf and stem fraction (p=0.223) while weed biomass was higher in plots with the black *Mucuna* type (p=0.042), presumably due to the poorer *Mucuna* growth.

In conclusion, no difference in the biomass production could be seen between the white and the mottled *Mucuna* types. The black type produced less biomass both years. Though such differences can partially be attributed to the poorer germination of the black *Mucuna* type, it seemingly also reflects somewhat poorer production and slower development of this variety.

Table 7-4. Biomass of three *Mucuna* varieties. Data are means across five fields in 1997.

Variety	Leaf+Stem	Mulch	Pod	Weed	Mucuna+ Mulch
	kg ha^{-1}				
White	2 330	4 100	240	660	6 670
Mottled	2 570	4 000	260	550	6 800
Black	2 060	2 800	20	1 070	4 900
Contrasts and p-values:					
W+M vs. B	0.223	0.009	<0.001	0.042	0.005
W vs. M	0.517	0.778	0.595	0.649	0.832

Winter Maize Trial

Winter maize yields were higher after a summer of *Mucuna* fallow than after a summer maize crop ($p<0.001$; Table 7-5). Throughout the growing season, *Mucuna* and no-*Mucuna* plots could be differentiated by maize color and height. Across fields, treatment with previous maize yielded 970 kg ha^{-1} while treatments with previous *Mucuna* averaged 50% more, 1460 kg ha^{-1}. Both yield levels are unusually high for winter maize in the study villages, attesting to favorable winter growing conditions and the generally high production levels in some fields. The average 50% yield increase came after a long 10-d lag time between *Mucuna* slashing and winter maize planting, as a dry period forced postponement of the maize planting. Such yield increase by *Mucuna* is typical to ones reported in the literature in the rotational systems (Lathwell, 1990; Lobo Burle et al., 1992; Cahn et al., 1993). The treatment where winter maize was planted after the white *Mucuna* type averaged 1630 kg ha^{-1}, while treatments after the mottled type yielded 1460 kg ha^{-1}, and after black type yielded 1290 kg ha^{-1}. Therefore, ranking of the yield in the *Mucuna* systems follows the ranking of the *Mucuna* biomass in these plots during the *Mucuna* variety trial. However, the contrast between white and mottled *Mucuna* types was not significant (p=0.185). In contrast, the maize yield after white and mottled *Mucuna* exceeded that after black *Mucuna* type (p=0.022).

Maize production differed among fields (p< 0.001) and there was a field-by-treatment interaction (p=0.062). The highest-yielding field averaged 2560 kg ha^{-1}, while the lowest-yielding field produced 670 kg ha^{-1}. At the field level, the percentage increase in yield as a result of added *Mucuna* ranged from 32 to 86%. In two of the experimental fields, however, no difference between the treatments with prior *Mucuna* and prior maize was detected through contrasts. In one of these fields, the area where the block was located seemingly included great variability, while the other, was greatly affected by winds, and the resulting lodging may have obscured the treatment response.

Table 7-5. Winter maize yield after three sole-cropped *Mucuna* varieties. Data are means across 10 fields in 1996.

Treatment	Maize yield (kg ha^{-1})
White	1 630
Mottled	1 460
Black	1 290
Control	970
Contrasts and p-values:	
W+M vs. B	0.022
W+M+B vs. C	<0.001

The ear leaf N concentration was slightly higher in the *Mucuna* treatments than in the no-*Mucuna* control (p=0.026), but P was higher in the control (p=0.053; Table 7-6). These average figures are, however, very low, at 2.2 and 0.20% for N and P, respectively.

Even with the additional N from the *Mucuna* mulch, the maize in the trial was clearly deficient, presumably as a result of poor soil fertility and growing conditions in the winter period.

Conclusions

Productivity of the Three *Mucuna* Varieties

It is clear that all three *Mucuna* varieties are able to generate large amounts of biomass under System C conditions. There were no differences between the white and mottled types, and although white and mottled were higher yielding than black, differences were relatively small. These results confirm the field observation that the choice of *Mucuna* variety has a relatively small impact on biomass production.

Table 7-6. Winter maize ear leaf nutrient concentration after three sole-cropped *Mucuna* varieties. Data are means across 10 fields in 1996.

System	N	P
	%	
White	2.2	0.19
Mottled	2.3	0.20
Black	2.2	0.19
Control	2.1	0.21
Contrasts and p-values:		
W+M vs. B	0.411	0.832
W+M+B vs. C	0.026	0.053

In 1996, biomass production averaged 7.9 t ha^{-1} for the white and mottled types, while for the black type it averaged 6.9 t ha^{-1}. *Mucuna* performed well even in fields with low fertility, producing approximately 5 t ha^{-1}, confirming its good performance in poor soils (Soil Fertility Network, n.d.). However, this study also confirmed earlier studies that indicated that *Mucuna* biomass production is higher in soils with higher fertility (Tian and Kang, 1998). In 1997, average biomass production was slightly over 1 t ha^{-1} lower than in 1996 for the white and mottled types, and about 2 t ha^{-1} for the black types. The lower biomass production of *Mucuna* with black seed during both of the study years indicates that its production potential is somewhat lower. A similar observation has been made by farmers in Oaxaca, where *Mucuna* has been spontanouesly adopted (Narváez and Paredes, 1994). In this study lower biomass production was caused in part by the black variety's lower field germination. The somewhat lower production is seemingly caused by morphological and phenological differences as well.

The similarity of biomass production of white and mottled types, and the fact that except for their seed, they are virtually indistinguishable from each other, raises the possibility that no other difference between them exists. Indeed, at the time of the completion of this thesis, data became available from a 1-yr characterization trial at IITA where the *Mucuna* varieties from Veracruz were included (Carsky et al., 1998). According to the study, both mottled- and white-seeded *Mucuna* produced seed that were 50% white and 50% mottled, while the black-seeded *Mucuna* produced seed that was only black. The characterization trial also confirmed another observation of the current study: the somewhat slower time to flowering of the black variety (158 d) in comparison to the white (143 d) and mottled (146 d). As mentioned earlier, the cultivated *Mucuna* types have yet to be classified in a detailed way.

Impact of *Mucuna* on Maize Yield in System C Conditions

The 1996 data confirm the findings of the maize system trial on the potential for large relative winter maize yield increases under System C conditions. Such high main crop yield response has been reported in the literature (Lathwell, 1990; Lobo Burle et al., 1992; Cahn et al., 1993). In comparison to the control plots where summer maize had been planted, increase in winter maize yield was approximately 30, 50, and 60% in the black, mottled and white plots, respectively. However, as discussed in Chapter 6, climatic factors make the winter season risky. Such riskiness was clearly demonstrated during the period of this study in that the 1995-96 winter season was unusually dry and maize yields were very low or, in many fields, non-existent. The following winter maize cycle offered good growing conditions, but again in 1997-98, the growing season was so dry that winter crops failed in many fields. Despite the apparent soil conservation benefits of System C and its congruence with the traditional practice of not burning fields prior to winter maize planting, its future potential is questionable.

CHAPTER 8
CONCLUSIONS

This study successfully quantified maize and *Mucuna* production, as well as the management and environmental conditions of such production, in a large number of farmer-managed fields. An observational method, agronomic monitoring, was utilized to accomplish this. Through on-farm trials, this study also quantified maize and *Mucuna* performance in both farmer-managed and alternative maize-*Mucuna* systems. The assistance of farmers during times of intensive data gathering allowed data collection from a large number of fields in logistically difficult conditions.

Though the impact of several management factors on maize and *Mucuna* production was successfully quantified through monitoring, the analysis was not always conclusive, and the impact of several environmental factors could not be demonstrated. Moreover, the impact of *Mucuna* on summer maize production in farmer-managed fields could not be conclusively determined, though it was clear from the analysis, field observations, and from data obtained in the trials, that such impact, if any, was not strong.

This study also attempted to evaluate the strengths and limitations of a relatively little-used methodology of on-farm agronomic research, namely, agronomic monitoring, in challenging conditions with high environmental diversity, and recent, unsure adoption patterns. This methodological evaluation was conducted by comparing the effectiveness of agronomic monitoring to another, more commonly utilized method of agronomic research: on-farm experiments. To pursue the evaluative objectives of this study, these on-farm trials were designed to mimic the management and environmental conditions of the farmers in the region.

As discussed in Chapter 3, adoption of the maize-*Mucuna* systems in the Los Tuxtlas region of southeastern Veracruz has fallen short of what had been hoped for, despite the dedication and hard work of farmer-extensionists and the staff of the Proyecto Sierra de Santa Marta. It should, of course, be noted that overnight successes of adoption can seldom be expected, and there are cases where adoption of a technology has first been slow, but later became overwhelming. Such adoption trends do, however, point to the need to evaluate the agronomic and biological factors surrounding the technology.

This concluding chapter will begin by reviewing findings on maize and *Mucuna* productivity in the farmer-managed systems. Then, drawing data from both the observational and experimental components of the study, it will discuss the four maize-*Mucuna* systems evaluated, and factors impacting the performance of these systems. In this context, the impact of *Mucuna* on summer and winter maize production will be assessed. Such factors may have wider relevance for on-farm performance of green manure/cover crop systems (GMCC) in on-farm conditions. This chapter will subsequently review the limitations and strengths of this study by discussing the impact of the chosen design and methods on the eventual data and insights that were obtained. Simultaneously, an assessment of the two methods utilized in this study, agronomic monitoring and on-farm trials, will be presented. Such discussion will, it is hoped, aid other researchers who are determined to evaluate complex systems in diverse and operationally difficult conditions. Thereafter, this chapter will recommend improvements and further research areas for the region's farmers and technical staff working to improve the smallholder maize systems. Finally, this chapter will conclude by suggesting areas for further research on *Mucuna* systems.

Farmer-Managed *Mucuna* and Summer Maize in the Los Tuxtlas Region: Their Productivity and Affecting Factors

The average *Mucuna* biomasses in the Los Tuxtlas region are relatively low, but highly variable. Average live biomass without mulch remained under 2 t ha^{-1} both years; in 1996, the average biomass with mulch was 4.3 t ha^{-1}. The variability of such biomass was striking; for all fractions measured, standard deviations were high, ranging from 65 to 118 % of their means. In contrast, in the farmer-managed system of the Atlantic Honduras, biomass variability has been reported to be very low, only 17 % of the mean (Triomphe, 1996; Buckles et al., 1998). As discussed in Chapter 2, in Buckles and Barreto's (1996) analysis of GMCC systems, relatively higher biomass variability is a characteristic of the more intensive simultaneous- and relay-intercropping systems.

Several management factors were shown to impact *Mucuna* biomass production in the region. Factors impacting biomass positively were the utilization of System B and higher plant density. The impact of environmental factors on biomass production was not successfully quantified, but field observations lent support to the importance of soil fertility. Though it was expected that due to differences in environmental conditions, there would be a village effect on *Mucuna* production, this was not the case, presumably due to the large variability among fields in a village, and the differing management practices in the villages.

The average summer maize yields measured in the monitoring plots were low, averaging 1090 and 1150 kg ha^{-1} in the two study years, respectively. Yield components most closely associated with yield were the number of ears per hectare, number of ears per plant, and ear weight. The relative unimportance of plant density was seemingly related to the large variability in the number of ears produced per plant, which on average was low (0.54 and 0.56), but highly variable. Maize yield in plots where less than 40% of plants produced ears was only about one half of that in plots where more than 60% of plants produced ears.

Management factors impacting summer maize yield positively were low weediness score and high plant density. Field observations also supported the importance of lowering the number of maize plants per hill, but the impact of this factor was not able to be quantified, presumably due to its association with soil fertility. Among the environmental factors, the study was able to clearly quantify the negative impacts of pests and disease on summer maize grain yield.

Maize-*Mucuna* Systems in the Los Tuxtlas Region

The performance of the maize-*Mucuna* systems in the Los Tuxtlas region of southeastern Veracruz exhibit the real-world constraints which prevent GMCC systems from functioning at their ideal potential. The following review focuses on the agronomic performance of the systems studied, as well as factors impacting on such performance.

In System C conditions, favorable summer climate and sole cropping enabled a high *Mucuna* biomass production (averaging 7.5 t ha^{-1}, and 160 kg ha^{-1} of N in 11 fields in 1997), high relative maize yield increases (averaging 50 to 120% yield increases in comparison to plots with previous summer maize), and seemingly superior potential to restore degraded soil. These features, though promising, may mean relatively little, since climatic factors make the winter season, this system's main crop season, exceedingly risky. Indeed, the relative maize yield increases of System C may amount to only 200 kg ha^{-1} during a particularly unfavorable winter cycle, which clearly is not enough to compensate for the total loss of summer maize production, nor for the increased labor involved in *Mucuna* cultivation. However, this study did not quantify residual effects of this system on the following summer maize yields. If such effects exist, it remains to be seen whether this system may have potential as an improved fallow of 1 to 2 yr, during which a risky but typically low-yielding winter maize crop could be harvested.

Mucuna biomass production in System A conditions was highly variable, but on average low (averaging 3230 kg ha^{-1} for the combined leaf+stem+mulch component in the observational conditions in 1996). Nitrogen content of the system under experimental conditions was approximately 50 kg ha^{-1}. Maize shading, short *Mucuna* growing season, a relatively late planting date, and low planting density contribute to such low *Mucuna* biomass. Despite this, System A clearly improved winter maize yield under experimental conditions (averaging 50% in experiments). Although *Mucuna*'s benefit to winter maize yield is less than in System C, System A enables the cultivation of summer maize, greatly increasing total annual yields relative to System C. However, it is not known what the trends for summer and winter maize yields would be beyond the scope of this 2-yr study. Yields may decrease due to the large quantitities of nutrients removed through maize double-cropping and the relatively low inputs of nutrients from the *Mucuna* biomass.

Moreover, neither under observational nor experimental conditions were any clear increases in summer maize yield detected.

System B, the most prevalent of the farmer-managed system, is designed to enhance *Mucuna*'s impact on summer maize yield, the main maize cycle in the area. However, despite the fact that *Mucuna* biomass production was greater than in System A in both farmer-managed fields (leaf+stem+mulch averaged 3.6 t ha^{-1}) and in experimental plots (averaging 5 t ha^{-1}), no clear, strong impacts on summer maize yields were found. This was true under observational conditions (encompassing the first 4 yr of *Mucuna* use) and under experimental conditions (focusing on the first 2 yr of use).

Several factors may explain the lack of detectable impact of *Mucuna* on summer maize yield in Systems A and B. These include recency of *Mucuna* use in the study area, the practice of burning residues, and the relatively low nutrient content of *Mucuna* in the systems. In System A, most of the nutrient mineralization presumably occurs during the winter cycle, while in System B the potential for large nutrient losses may result from the long time lag between *Mucuna* senescence and summer maize planting. Such factors could be further quantified only through focused studies on the nutrient dynamics of the farmer-practiced studies, a topic beyond the scope of the present study.

The Effectiveness of Agronomic Monitoring

It was hoped that agronomic monitoring would yield both descriptive data on the performance of maize and *Mucuna* as well as quantitative information on the factors impacting such growth. The monitoring tool was clearly more effective for the first task, acquiring descriptive data. Reliable estimations of maize yield were made in a large number of fields, and data on *Mucuna* growth were obtained. In the second year of the study, purposely selected representative quadrats were utilized to measure *Mucuna* biomass, which better estimated actual biomass than randomized sampling, due to the large within-plot variability.

The agronomic monitoring technique was less effective in identifying factors that impact performance of maize and *Mucuna* in the region. Though the impact of certain environmental and management factors was quantified, in other cases effects on maize-*Mucuna* production were not clear. The large variability of on-farm conditions, and consequent difficulty of elucidating causal relationships in on-farm conditions is well-known (Swinkel et al., 1996; Mutsaers et al., 1990). In this study, the problem was worsened by severe constraints on the ability to select study fields and large within-field variability. Despite the fact that much of the variability in performance was on the field level, the field could not be characterized adquately enough to permit assessment of the impact of field-level factors on *Mucuna* biomass and yield. At the village level, both management and environmental factors were highly variable, which created difficulty in discerning village-level effects on system performance. In similar future studies, several alternatives to grouping at village level may be considered, such as grouping fields according to biophysical criteria or according to socioeconomic characteristics of their owners.

The monitoring could not conclusively demonstrate whether *Mucuna* has any impact on maize yield in the region, due to the large within-field variability in management and environment. However, the study did show that, if such impacts exist, they are on the average relatively small.

The study does call into question the cost-effectiveness of agronomic monitoring to quantify causal relationships in such diverse environments where little selection of any kind can take place. The field work was very labor-intensive due to the large distances between fields and villages, and due to the numerous visits to each field. Agronomic monitoring could have been modified in several ways to improve its effectiveness. First, the odds of quantifying causal effects could be increased by visiting the monitoring plots at the biologically most meaningful times, e.g., at maximum weed pressure, rather than at fixed intervals. However, such a method would have been even more time intensive, such that only a very limited number of fields located in just one to two villages could have been monitored. Second, a "lighter" agronomic survey could have been utilized that would have consisted of selected sampling of *Mucuna* biomass and maize yield in a large number of fields; this approach might have generated equally valuable data more cost-effectively, if combined with farmer interviews and on-farm experiments mimicking farmer conditions. Finally, a more flexible approach to monitoring could have been adopted. For example, work could have focused on locations with particular good or poor growth of maize and *Mucuna*. The size of the sampling areas could have been variable and even consisted of only a few square meters. Research could then have focused on elucidating the causes of high or low performance in the sampling unit. Such research could have utilized a number of tools: farmer interviews (to elicit farmer's hypotheses of factors impacting crop growth as well as the farmer's past management of the crop), soil sampling (to reveal chemical and physical factors impacting crop performance), and agronomic measurements (to quantify management and environmental factors in the location). Such work could have taken place over several cycles, and its results could have been later tested in on-farm trials.

Strengths and Shortcomings of the Experiments

The on-farm trials were designed to pursue the evaluation of the local maize-*Mucuna* systems in more controlled conditions, and to expand the evaluation to the winter maize cycle. In addition, they sought to compare the yield impacts of the local maize-*Mucuna* systems (A and B) to the impacts of an alternative rotational maize-*Mucuna* system (C), a system with a winter *Mucuna* intercrop (system D), and to a no-*Mucuna* control.

The trials were generally quite successful. They allowed quantification of production under the maize-*Mucuna* systems in comparison to a local maize system without *Mucuna*. The trial management successfully mimicked farmer management, as evidenced by the fact that average maize yield and *Mucuna* biomass in the trials were very close to farmer averages. (However, the trials did not duplicate the extreme variability in farmer management practices--not that this would have been necessarily desirable!.) Moreover, the trials were quite cost effective, in that a relatively large number of trials and fields were managed with relatively little cost, and were pursued parallel to the monitoring activities.

Though generally successful, the trials did suffer from a number of shortcomings. Some of these are general to on-farm research in conditions where environmental and management variability is high; others are due to the short-term duration of the research project; and finally, some were specific to this research project, due to its operational environment and its design. In the following, such shortcomings are reviewed in the hopes that this will benefit others working in similar conditions.

On-farm trials suffer from a number of well-known limitations. The high variability of environmental conditions necessarily limits the number of treatments. In this study, four treatments was estimated to be the highest number feasible, and in several fields suitable block locations were found only with difficulty. Moreover, the labor-intensive nature of on-farm work, with a great deal of time spent traveling from one field to another, limited the number of measurements. The choice was made to work in several fields, but to limit measurements over the growing season.

Such constraints necessarily limited the scope of the experiments, to the neglect of several important research issues. For example, in the maize-*Mucuna* system trial, two additional no-*Mucuna* treatments, one with summer maize+winter fallow and another with winter maize+summer fallow, could have greatly increased understanding of the impact on maize yield of *Mucuna* versus unimproved fallowing. Similarly, the winter maize trial would have benefitted from an additional no-*Mucuna* treatment with summer fallow. Moreover, the experimental focus remained limited to *Mucuna* and maize production, with no attempt made to study *Mucuna*'s impact on soil nutrient or water status.

The short, 2-yr duration of the research project had several consequences. Only two summer and winter cycles were covered by the maize-*Mucuna* system trial, two summer cycles in the *Mucuna* variety trial, and one winter cycle in the winter maize trial. Both winter cycles were unusual: the first unusually dry, the second unusually wet, and we therefore lack data on *Mucuna*'s impact on winter maize in a typical winter cycle.

Ideally, management of the maize-*Mucuna* systems would have been stable throughout the study. In practice, the short duration of the study and the recency of *Mucuna* use meant that system management remained something of a moving target as farmers and the researcher alike underwent a learning process. Specifically, in 1995 *Mucuna* in the system trial was slashed late November with hopes that the water-conserving benefits from *Mucuna* would offset the declining rainfall. This date was found to be clearly too late for winter maize planting that year, and too risky generally. In the second year, slashing date for *Mucuna* was moved two weeks ahead with beneficial results. In addition, the winter *Mucuna* in System D was planted in December 1995, which seemingly was risky and too early as *Mucuna* overwintered poorly, but in one field produced pods by April 1996. That system was discontinued, and System C was substituted in the trial instead.

As the number of regional farmers and fields utilizing *Mucuna* was limited, fields were chosen for the trial through a process of elimination rather than selection. For example, for a field to be included in the maize-*Mucuna* system trial, the first *Mucuna* planting had to be that year, and the area planted with *Mucuna* had to be large enough to hold the trial. Of necessity, no process was followed whereby representative fields were chosen. However, on the whole, the experimental fields accurately reflect the general conditions in the region. An exception to this may be the maize-*Mucuna* system trial, where two of the four fields had unusually poor fertility.

Certain decisions concerning the trial design, made to accommodate available resources and the complexity of the production systems, do undermine to some extent the trials' representativeness of farmer circumstances. First, it was decided to omit the common practice of burning fields prior to summer maize planting. This was done in part to limit the number of treatments, and in part to avoid the complexity of the burning practice, as some farmers burn their fields thoroughly, others in patches and superficially. Second, many farmers rotate the areas under *Mucuna* in their fields, a practice not duplicated in the trials. Farmers may thus never accrue the second-year effects studied in the maize system trial.

Finally, neither the trials nor the monitoring included formal farmer participation. The research objectives and design were determined by researchers. The farmer input in the research process was informal, taking place during the many field and home visits, as well as during the numerous occasions when the farmers assisted the researcher in the more labor-intensive measurements. The lack of formal farmer participation in the study was mainly caused by the process of academic research, wherein the research objectives are determined before the initiation of the field work. More formal farmer participation could, however, have enhanced the quality and relevance of this study.

Issues for Further Development of the *Mucuna* Systems in the Los Tuxtlas Region

Utilization of *Mucuna*, and research- and development-related activities surrounding maize-*Mucuna* systems, are ongoing in the Los Tuxtlas region. Farmers and project personnel are experimenting with components of the current farmer-utilized systems and with alternatives to it. As mentioned in Chapter 3, a government agency plans to buy a large amount of *Mucuna* seed from the region's farmers in 1998 for extension efforts elsewhere. Though markets for *Mucuna* seed can positively impact *Mucuna adoption* in the short term, in the long term such adoption will necessarily rest on soil conservation benefits that can be realized as improved main crop yields, and/or the marketability of *Mucuna* for other uses.

From the perspective of improving the sustainability and productivity of the smallholders' maize systems in the Los Tuxtlas region, this research recommends changes in maize and *Mucuna* management, and increased research on the potential of System C. Specifically, the following should receive special emphasis:

- *The importance of timely and correct management of Mucuna*: In all systems, *Mucuna* growth is favored by early planting in a weed-free field and by higher planting densities. Such factors may have a particularly strong impact on *Mucuna* biomass grown under System A conditions, in which the growing period of *Mucuna* is particularly short. In the most intensively-managed fields with two maize cycles, *Mucuna*'s impact on winter maize yields could be maximized through such improvements.
- *Modifications to maize planting pattern and density*: Higher total densities of maize should be utilized, but only by altering current planting pattern (i.e., farmers should plant more hills per ha, but fewer plants per hill). Two maize plants per hill should be utilized, which would require not only good field germination, but germination tests prior to planting.
- *Modifications to maize and Mucuna management in System C*: Local field trials should be conducted on the impact of increased *Mucuna* planting density, and earlier slashing and winter maize planting date, along with the potential of the utilization of short-season maize varieties and small inorganic

fertilizer additions. As discussed earlier, System C potentially offers high relative yield increases and relatively good soil conservation, but its potential is limited by the difficult winter growing conditions. Increased *Mucuna* planting density would likely produce good ground cover and biomass production earlier. Planting winter maize 1 month earlier may avoid some of the risks associated with winter maize production. Some research on the impact of short-season varieties and small inorganic fertilizer additions on winter maize yield has been conducted in the region, and such research should be continued.

- *Potential of System C as a multi-year fallow*: Investigation should focus on the impact of 2- to 3-yr fallow under System C conditions during which a winter maize crop could be harvested. Such research should focus on the residual impact of *Mucuna* on soil.
- *Potential of dry-season Mucuna survival*: Research in the region has correctly continued to assess the dry-season performance of the various *Mucuna* varieties.[1] Such research may eventually lead to the identification of varieties that could generate sufficient biomass prior to summer maize planting (System D). It could also lead to an earlier and higher biomass production under sole-cropped summer conditions before winter maize planting (in conditions resembling System C).

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[1] Doroteo Chima and Balente Herrera from Proyecto Sierra de Santa Marta have been conducting this work.

Issues for Further Research on *Mucuna* Systems

This research pointed out several important future research areas in *Mucuna* systems. From a research/development perspective, the following research areas would seem to be particularly worthwhile:

- *Assessment of nutrient dynamics in relay-intercropped or simultaneously-intercropped Mucuna systems which have a dry season-induced time lag between the Mucuna senescence and next main crop planting.* The following issues should receive particular attention:
    - Avenues of nutrient loss in field conditions during the dry season, including N volatilization and mulch loss.
    - Dynamics of mulch formation and its impact on soil nutrient status, temperature, and moisture in intercropped systems as compared to sole-cropped *Mucuna* systems.
- *Further assessment of the performance of Mucuna systems in different biophysical and socioeconomic conditions.* Such assessment should include both biophysical and socioeconomic factors, and should be conducted from the perspective of both researchers and farmers. Eventually, such assessments should be conducted with a view to identifying strengths and limitations of particular systems in different niches;
- *Assessment and improvement of the food and feed potential of Mucuna, including studies on the feed and food value of various fractions (e.g., foliage, seeds), as well as development of other potential marketable products from it*;

- *Assessment of soil conservation benefits at different levels of harvesting of other products from Mucuna*;
- *Screening and breeding efforts to enhance the performance and adoption potential of Mucuna.* Specifically, following issues should receive particular attention:
    - Increase in biomass production in poor fertility soils and during dry season; and
    - Reduction of L-dopa concentration of *Mucuna* seed; and
- *Socio-economic assessment of the costs and benefits of maize-Mucuna relay intercropping*, given the large variability of the system in on-farm conditions. Particular attention should be paid to costs and benefits to farmers with differing resource levels.

It is anticipated that such research efforts would have wider relevance to GMCCs in general.

APPENDIX A
FERTILIZER TRIALS

Nitrogen Trial of 1995

Overview

The purpose of the N trial was to analyze the maize yield response to N fertilization in farmer conditions. This trial was conducted in 1995 only.

Materials and Methods

The N trial was conducted in four fields located in La Candelaria. The was superimposed on summer maize fields in which farmers had planted traditional varieties from 14 to 16 June. It followed a RCB design with six replications per field. Plot size was 4 m by 4 m. Treatments were three N levels applied as urea granules (46% N): 0 kg ha^{-1} (0 N), 50 kg ha^{-1} (50 N), and 100 kg ha^{-1} (100 N). For each N treatment, one-half of the N was applied at the base of each maize hill with a machete at approximately 2 WAP; the second half was applied in similar fashion at approximately 6 WAP. Plots were weeded twice during the growing season. Maize was harvested 6 to 7 Nov. 1995, following the procedure presented in Chapter 5.

Results and Discussion

Added N had no effect on maize yield in the four fields studied in 1995 (p=0.587). Performance did vary by field, however (Table A-1). In one field, maize yields were actually lower with the higher amount of N fertilizer than with no fertilizer.

Table A-1. Maize yield as affected by nitrogen in four locations in 1995.

Nitrogen	Field 1	Field 2	Field 3	Field 4
	----------------- kg ha^{-1}	----------------------		
0 kg ha^{-1}	1270	1310	1400	2000
50 kg ha^{-1}	1160	1230	1120	2270
100 kg ha^{-1}	1520	1330	1000	2170
Contrasts:				
0 vs. 50	0.512	0.205	0.148	0.286
0 vs. 100	0.148	0.967	0.038	0.466

The absence of a beneficial response to N in 1995 may be associated with several factors. First, rainfall in 1995 and 1996 was erratic, and periods with no rain coincided with the time of fertilizer applications in late June and late July. In both instances, periods of very heavy rainfall followed several days later. In general, farmers in La Candelaria report chronically erratic benefits from N, which presumably is related to weather factors. Second, within-field variability may have caused differences in the soil fertility within blocks. Finally, in the one field with apparent negative effects of N, high winds in late October caused heavy damage, compromising the accuracy of harvest measurements.

Nitrogen and Phosphorus Trial

Overview

The purpose of the N and P trial was to further examine the response to inorganic fertilizers in the study area. Since no N response had been obtained in 1995, P was added in the trial to see if it was the most limiting nutrient. This trial was conducted in 1996 only. The fertilizer trials also represented a limited exception to the principles outlined above. In those trials, in order to explore the potential of fertilizer response, the amounts of fertilizer employed were higher than those used by the few fertilizer-using farmers.

Materials and Methods

The trial was conducted in three fields located in La Candelaria. As with the N trial, this trial was superimposed on maize fields which farmers had planted with traditional varieties from 12 to 16 June 1996. The trial design was a 2^2 factorial arranged in a randomized complete block design, with three replications per field. Plot size was 4 m x 4 m. Treatments were: (1) 0 NP; (2) 0 N; 20 kg ha^{-1} P (as triple superphosphate; 47% P_20_5); (3) 0 P, 100 kg ha^{-1} N; and (4) 100 kg ha^{-1} N and 20 kg ha^{-1} P. On 23 June (at approximately 10 DAP), P and the first split application of N (50 kg ha^{-1}) were applied in a hole made with a machete at the base of each maize hill. At approximately 6 WAP, the second split application of N (50 kg ha^{-1}) was made. Plots were weeded twice during the growing season. Maize was harvested 6 to 7 Dec. 1996, following the methodology presented in Chapter 5.

Results and Discussion

In the three experimental fields summer maize yields averaged 990, 1200, 1230, and 1760 kg ha^{-1} respectively with 0 NP, P, N, and NP. Both N and P had clearly significant ($p<0.001$) and positive impact on summer maize yields in 1996. There was also strong evidence of an interactive effect between N and P ($p=0.079$, Table 15). With no P, response to N averaged 240 kg ha^{-1} across the three fields and was not clearly significant ($p=0.133$), while with added P, yield response to N was 560 kg ha^{-1} ($p=0.001$). The response to P mirrored these results: with no N, maize yield exhibited only a slight positive trend (by 210 kg ha^{-1}, $p=0.195$), while in the presence of N, response to P was clearer, 530 kg ha^{-1} ($p=0.003$). Response to P varied by field ($p=0.013$, Table 16), with maize yield averaging 50, 320, and 740 kg more with than without P in fields 1, 2, and 3, respectively. Yield with and without P did not differ significantly within field.

Table A-2. Maize yield as affected by nitrogen and phosphorus in 1996. Data are means across three locations (fields).

	N0	N100	Contrasts: N0 vs. N100
P0	990	1230	0.133
P20	1200	1760	0.001
Contrasts: P0 vs P20	0.195	0.003	

In summary, nitrogen clearly limited maize yield in all of the three study fields, while phosphorus seemingly limited maize yield in two of the three fields. Interactive effects of N and P were strong and clear, attesting to the fact that highest maize yield increases were attained by applying both.

APPENDIX B
FACTORS IMPACTING *MUCUNA* PERFORMANCE IN THE LOS TUXTLAS REGION OF VERACRUZ

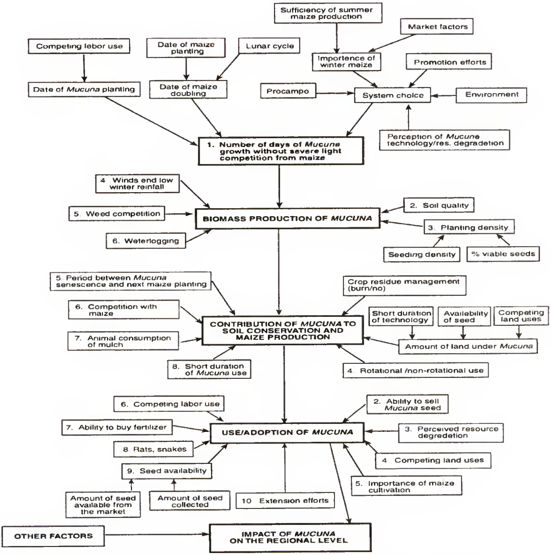
Sufficiency of summer maize production
Market factors
Competing labor use
Date of maize planting
Lunar cycle
Importance of winter maize
Promotion efforts
Date of *Mucuna* planting
Date of maize doubling
Procampo
System choice
Environment
Perception of *Mucuna* technology/res. degradation
1. Number of days of *Mucuna* growth without severe light competition from maize
4 Winds and low winter rainfall
5 Weed competition
BIOMASS PRODUCTION OF *MUCUNA*
2. Soil quality
3. Planting density
6. Waterlogging
Seeding density
% viable seeds
5 Period between *Mucuna* senescence and next maize planting
Crop residue management (burn/no)
6. Competition with maize
Short duration of technology
Availability of seed
Competing land uses
CONTRIBUTION OF *MUCUNA* TO SOIL CONSERVATION AND MAIZE PRODUCTION
7. Animal consumption of mulch
Amount of land under *Mucuna*
8. Short duration of *Mucuna* use
4 Rotational /non-rotational use
6. Competing labor use
2. Ability to sell *Mucuna* seed
7. Ability to buy fertilizer
USE/ADOPTION OF *MUCUNA*
3. Perceived resource degradation
8 Rats, snakes
4 Competing land uses
9. Seed availability
5. Importance of maize cultivation
Amount of seed available from the market
Amount of seed collected
10 Extension efforts
OTHER FACTORS
IMPACT OF *MUCUNA* ON THE REGIONAL LEVEL

Figure B-1. Factors impacting *Mucuna* performance in the Los Tuxtlas region of Veracruz.

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BIOGRAPHICAL SKETCH

Born in 1961 and raised on a small dairy farm in the village of Itäkoski in Northern Finland, Marjatta Eilittä attended primary and secondary schools in her home area. She then attended Harvard University in Cambridge, Massachusetts, where she graduated *magna cum laude* in History and Science in 1986; her thesis concerned local people's attitudes towards the construction of hydroelectric power plants in Northern Finland. After certain pleasant detours (including a year in Thailand studying deforestation and the birth of her first child), she studied at the University of Helsinki's Department of Plant Production from 1988 to 1992. For her Master's thesis, she studied factors explaining maize yield differences among smallholder maize farmers in the humid forest zone in southwestern Nigeria. Her research was conducted on farm while she was affiliated with the International Institute of Tropical Agriculture (IITA). In the fall of 1992, she began her Ph.D. studies at the University of Florida, where she also worked (1993-1995) as a project associate in the "Global Research on the Environmental and Agricultural Nexus" (GREAN) project. The dissertation field work was conducted in Mexico while she was affiliated with the Natural Resources Group of the International Maize and Wheat Improvement Center (CIMMYT).

Marjatta is married to Paul Psychas, MD. They have four children: Aleksis (born 1987), Miriam (1990), Hanna (1994), and Oscar (1998).

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Lynn E. Sollenberger

Lynn E. Sollenberger, Chairman
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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